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COMPILATION, METALLURGICAL LABORATORY TESTS ADVANCED TECHNICAL DEVELOPMENT EFFORT AND SPECIFIC SPACECRAFT

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GODDARD SPACE FLIGHT CENTER

GREENBELT, MD.

COMPILATION, METALLURGICAL LABORATORY TESTS ADVANCED TECHNICAL DEVELOPMENT EFFORT AND SPECIFIC SPACECRAFT

By
W. G. Grenier

January 1964

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

FOREWORD

A compilation of the Metallurgical and related tests, conducted during the period of August 1962 to January 1964, that were conducted by the Structural and Mechanical Systems Branch, Spacecraft Integration and Sounding Rocket Division, Space Sciences and Satellite Applications Directorate is herein contained.

The prime purpose of this document is to compile, under one cover, all Metallurgical and related studies conducted during the past 17 months by personnel of the Structural and Mechanical Applications Section. The tests have been in direct support of the A.T.D. effort and specific spacecraft programs. The studies consist of: spacecraft experimental component failure analyses, evaluation of Proprietary coating processes, and physical properties of specific alloys. In all cases conclusions made as a result of these tests were those of the Requestor or his Consultant.

William G. Grenier

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DATE IN	DATE COMPLETED	PERFORMED BY
12-6-62	12-11-62	W. G. Grenier

NAME OF TEST

Metallographic Examination

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Metallographic study of segment from S-6 Prototype skin to determine changes in grain structure.

EQUIPMENT INVOLVED:

Mounting press, polishing papers and wheels, Fisher vibratory polisher, Chrome Regia Soln., Marbles Soln., Unitron Metallograph, and Kentron Microhardnese Tester.

RESULTS:

1) At the Originators request, all data was submitted to Mr. C. E. Vest for evaluation.

2) See Enclosure -1, for photographic and metallographic presentation.

W. G. Grenier 12-12-62
(Signature) *(Date)*

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
J. B. Webb	S-6 Prototype	634S65-01	400-40

PROCEDURE:

A strip was sheared from submitted specimen parallel to line A-B, Figure 1, Enclosure 1, and mounted with the original fracture face exposed, in bakelite. Locations A + B were so marked on the mount.

The specimen was polished through the papers and first wheel. Final polish was accomplished on a Fisher vibratory automatic polisher. The specimen was etched with a Chrome Regia solution and photomicrographs at 200 magnifications were prepared, employing the Unitron metallograph. The specimen was then repolished through the papers and both wheels, finishing on the 1/4 micron diamond charged wheel. Etchant used was Marbles' reagent and photomicrographs at 100 magnifications were prepared.

Microhardness determinations were made using the Kentron microhardness Tester.

W. G. Grenier 12-12-62
(Signature) *(Date)*

S.R. No. 400-40, Segment Photographs.

S-6 Prototype failure study results.

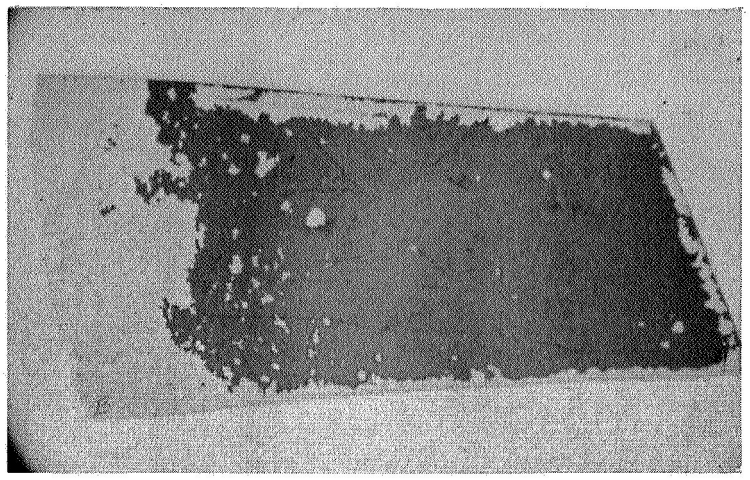

Figure 1-Interior Surface 1.65 X

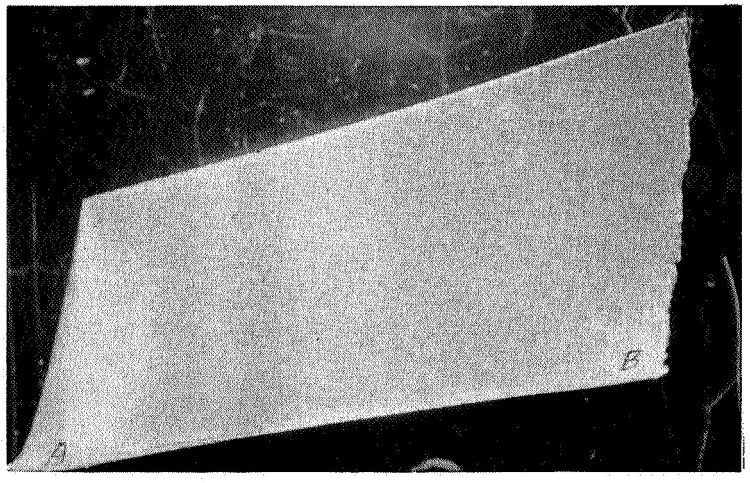

Figure 2-Exterior Surface 1.65 X

Above photos show configuration of segment from which sample was taken for metallurgical examination.

Strip was sheared from A to B, bent and mounted, with fracture surface face exposed, in bakelite. Ends A and B were labeled in mount.

S.R. No. 400-40, Photomicrographs. S-6 Prototype failure study results.

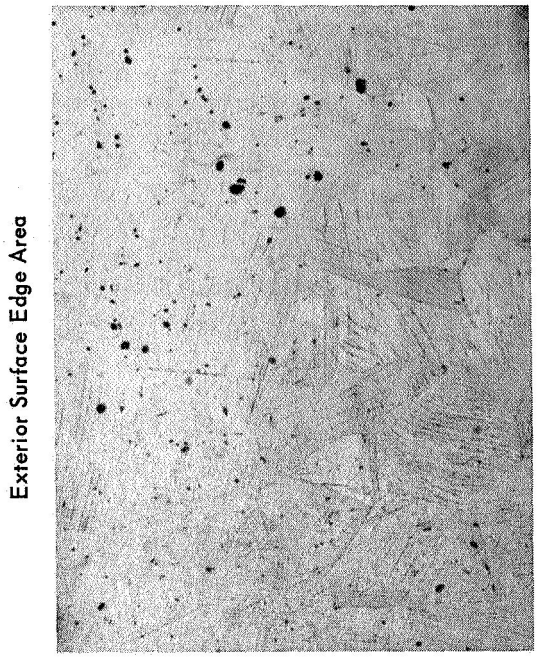

Figure 3-End A 200 X

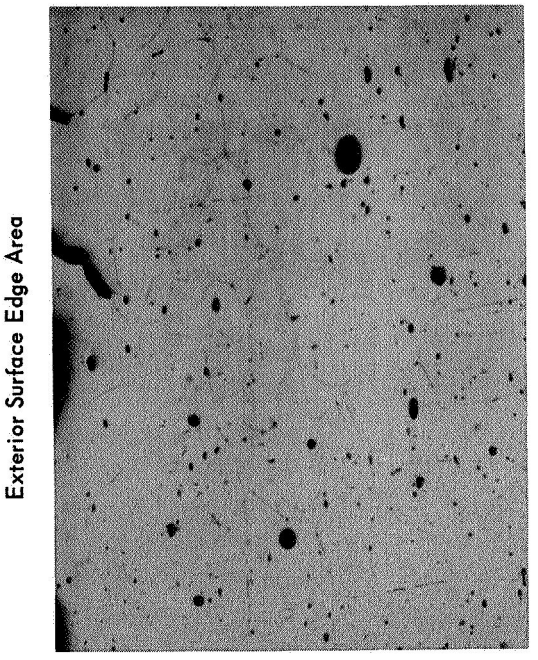

Figure 4-End B 200 X

(Chrome Regia Reagent)

Typical microstructure, as brought out by Chrome Regia. Final Polish obtained on Fisher vibrator automatic polisher.

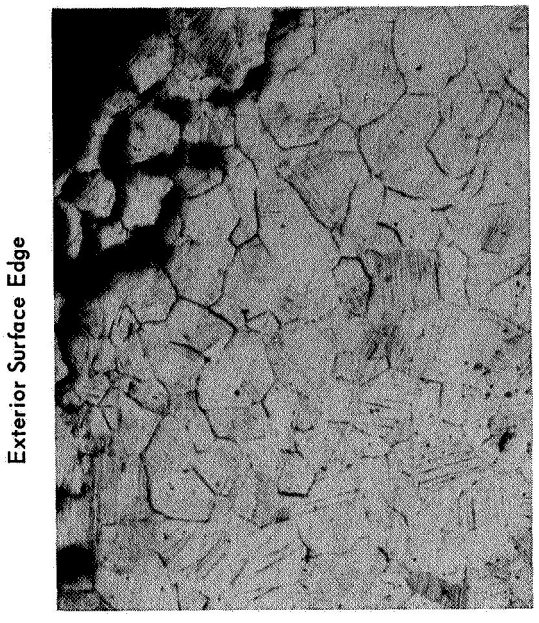

Figure 5-End A 100 X

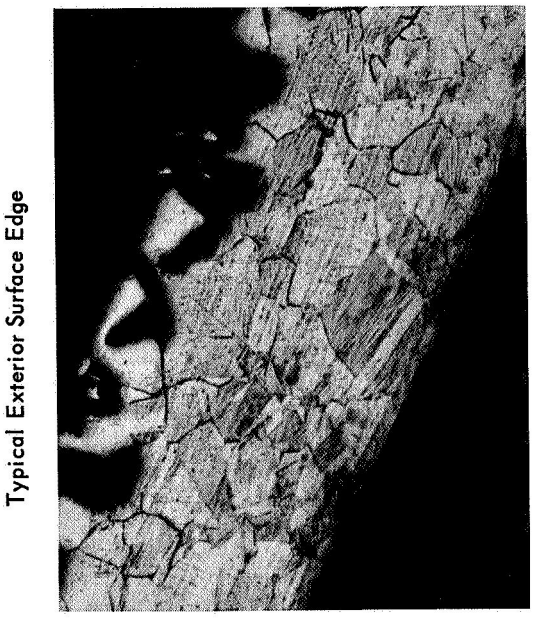

Figure 6-End B 100 X

(Marble Reagent)

Typical microstructure, as brought out by Marbles Reagent. Final polish obtained by hand on 1/4μ diamond lap. Same specimen as above, but repolished and reetched.

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
J. B. Webb	S-6 Prototype	634S65-01	400-40

CONCLUSIONS: The metallographic examination of the specimen shows strain lines typical of a material subjected to a very high strain rate such as Explosive Metal Forming; shown both transgranular and intergranular fracture with the latter predominating; shows an annealed microstructures; shows a clean microstructure (each of non-metallic inclusions); and shows that the piece failed from a force exerted from the inside.

It is concluded that the metal failed due to a force being exerted at such a very high rate that the material acted in a brittle manner instead of its normal ductile manner.

C. E. Vest
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C. E. Vest	Beltsville	125	S-17	673S69-01	S.R. 1000-15

DATE IN	DATE COMPLETED	PERFORMED BY
4-17-63	5-28-63	W. G. Grenier

NAME OF TEST

Analysis of failure of hi-nickel bellows

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

1) Prepare Macro-Photographs of good bellows and failed bellows to point up differences.

2) Prepare Macrographs of bellows fractures

3) Determine hardness of bellows material from fracture segments.

4) Test reaction of "Ruby Flux" to Ni, Cu, Al, and steel

5) Section failed bellows and prepare photomicrographs of microstructures.

EQUIPMENT INVOLVED:

Buehler Supermet mounting press, transoptic powder, cut off wheel, belt surfacer, Handimet hand polishing apparatus, 1st lapping wheel with 600 grit aluminum Oxide on silk, Kentron microhardness tester, slow lapping wheel, automet polishing attachment, 6μ diamond paste on silk cloth, 1/4 μdiamond paste on silk, Gamal Alumina on Micro-cloth, Unitron bench microscope, Nitric and Acetic acid solution, ultrasonic cleaning apparatus, Unitron Metallograph, B & L Model "L" camera, 72 mm-158mm and 48 mm lenses, Polaroid camera attachments and millimeter scale.

RESULTS:

1) The material tested is not of the hardness indicated by the literature.

2) Ruby Flux residue severely attacked all materials tested.

3) Microstructure is normal for electrodeposited material excepting in pit area shown in data as Fig. 12, sheet 11.

W. G. Grenier 6-6-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	S.R. 1000-15

PROCEDURE: Macro photographs of the failed bellows and a new bellows were prepared, using the Bausch & Lomb Model 'L' camera with Polaroid attachment.

Fracture segments of the bellows material were mounted in Lucite and polished through the first lapping wheel, using silk and 600 grit aluminum Oxide powder. Microhardness tests were performed using the Kentron Microhardness Tester. Photomicrographs were prepared of the specimen on the Unitron Metallograph. One photomicrograph at 200 diameters was prepared to show the hardness impression locations. One photomicrograph at 1067 diameters, of two of the hardness impressions was prepared for use in computing the D. P. N. mathematically as a rough check on the handbook data.

For facility in sectioning, the failed bellows was mounted whole in Lucite. During the high pressure stage of the mounting operation the bellows collapsed along its longitudinal axis. In spite of this, it was sectioned, using a thin cut off wheel. It was first sectioned longitudinally and the lucite dissolved from one half of the bellows. This half section was opened, the interior studied under high magnification, and submitted to the Originator for his perusal. The remaining half section was dissected into five different pieces and the various faces mounted in a single lucite mount. This mount was treated as follows:

1) Rough ground on belt surfacer

2) Hand polished through the 600 grit paper, wet.

3) Polished on slow wheel;

3.1 Low speed setting

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15

PROCEDURE:

3.2 Employ Automet Automatic polishing attachment

3.3 Employ 6μ diamond on silk cloth

3.4 Automet set at 40 pounds for 4 minutes

4) Cleaned, ultrasonically

5) Polished on slow wheel as in 3 above excepting:

5.1 1/4μ diamond paste on silk cloth

5.2 Automet set at 30 pounds for 2-1/2 minutes

6) Etched in 50/50 HNO_3 + Glacial Acetic Acid Soln.

6.1 Determined time by sight

7) Polished on Slow wheel at low speed setting

7.1 Hand polished

7.2 Abrasive – Gamal Alumina on Microcloth.

8) Continued polishing and etching until the true microstructure of the material was revealed.

Photomicrographs at 1000 diameters were prepared, using the Unitron Metallograph, in the polished and the etched conditions. Pitting on the interior wall of the bellows and the general microstructure of the material are pointed up.

One small sample each, of 410SS, M-10 steel, Al, Cu, and Ni, were subjected to exposure to Ruby Flux for corrosion study. The nickel sample was taken from a nickel plating electrode to closely simulate the material of the bellows. Macro photographs at

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15

PROCEDURE: 1-1/2 diameters were prepared prior to and at significant stages of the test. Approximately 25 cc of Ruby Flux was supplied by the Originator. Approximately 5 cc of this flux was placed in each of 5, 20cc glass specimen bottles equipped with screw on plastic caps. One different metal sample was placed in each of the bottles and the caps screwed down tightly. Each bottle was vigorously shaken to insure initial contact with the metal sample. Excepting the nickel sample, each sample was sufficiently long so only a portion was immersed in the Ruby Flux. The nickel sample was sufficiently small so it was completely immersed for the first 20 hours of the tests. For the next 24 hours it was carefully placed on end, such that a small portion was not immersed.

For the final 71 hours of testing, all samples were suspended within their respective specimen bottles, by a nylon thread. They were suspended such that no portion of any sample was touching the liquid Ruby Flux. The bottles were sealed in every case such that only the flux or the flux vapors were available to the metal samples. Each bottle was shaken to assure initial physical contact with the Ruby Flux. This tends to simulate the actual fluxing conditions in the interior of the bellows.

Macro photographs were prepared at 1-1/2 diameters at the various intervals to show the effect of the Ruby Flux on the specific materials. All samples were subjected to Ruby Flux exposure for 115 hours each.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15

DATA: Microhardness Test Data

Kentron Microhardness Tester

Indentor load = 25 grams

Objective = 50X, Multiplication factor = 0.2008

Reading No.	Average Length of Diagonals		Table Value	D.P.H.N.
	Filar Units	Microns		
1	76	15.26	7.983	199.8
2	76	15.26	7.983	199.8
3	77	15.46	7.783	194.8
5	76	15.26	7.983	199.8

Fig. 1-Table of Microhardness Test Data.
Material tested was fragment of failed bellows.
Reading No. 4 is considered to be unacceptable due to distortion of penetrator impression.

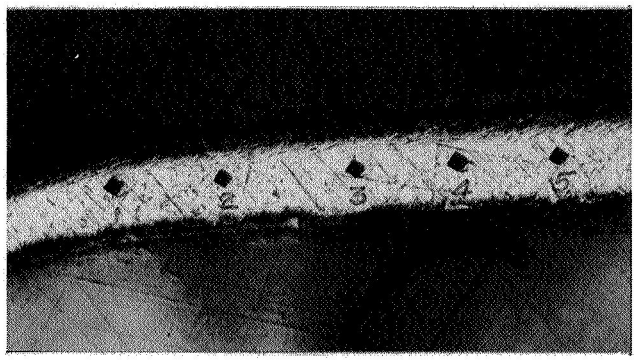

Fig. 2-Photomicrograph showing hardness impression locations on cross section of bellows segment. 200X.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15

DATA: Microhardness Test Data

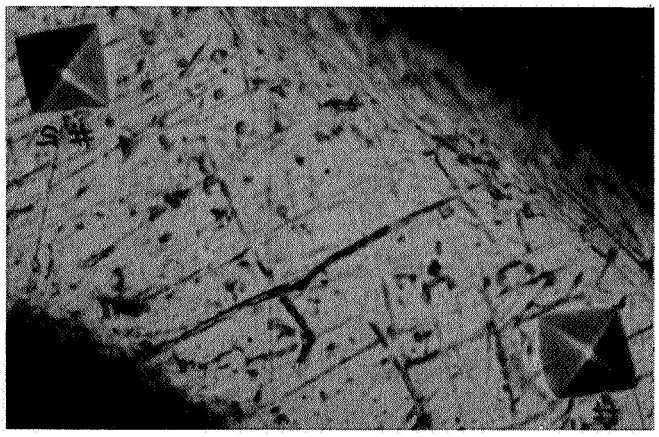

Fig. 3-Magnification =1067 Diameters

Photomicrograph of hardness impressions listed as reading numbers 1 and 2 in Figure 1. This photomicrograph was employed in mathematically calculating the D.P.H.N., as a check on the tabb values of Figure 1.

Formula: $D.P.H.N. = \frac{2L \sin a/2}{d^2}$ where L = load in kilograms
a = 136° apex angle of indentor
d = average of diagonals in mm.

$$\therefore \text{Impression No. 1, D.P.H.N.} = \frac{(2)\left(\frac{25}{1000}\right) \sin 68^\circ}{\left[\frac{15.4 + 17.2}{(2)(1067)}\right]^2} = \frac{(0.050)(0.9272)(1138489)}{16.4^2} = 197.8$$

$$\text{Impression No. 2, D.P.H.N.} = \frac{(2)\left(\frac{25}{1000}\right) \sin 68^\circ}{\left[\frac{16.9 + 16}{(2)(1067)}\right]^2} = \frac{(0.050)(0.9272)(1138489)}{(16.5)^2} = 193.9$$

The impression diagonals were measured on the photomicrograph using a conventional millimeter scale. Therefore the calculations corroborate the data presented in Figure 1.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15

DATA: Macro Photographic of Bellows

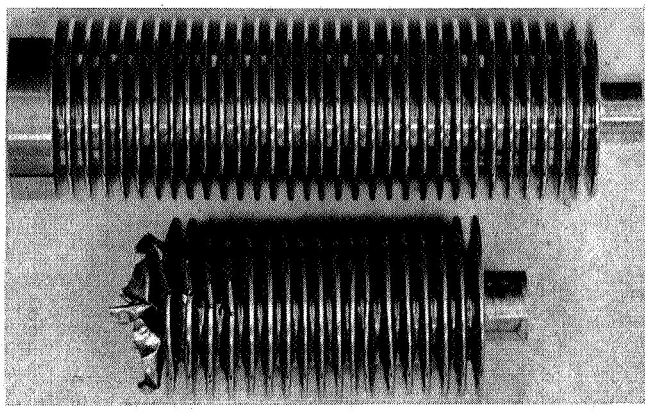

Fig. 4-Macro photo of new bellows, before soldering and failed bellows. 2-1/2 X.

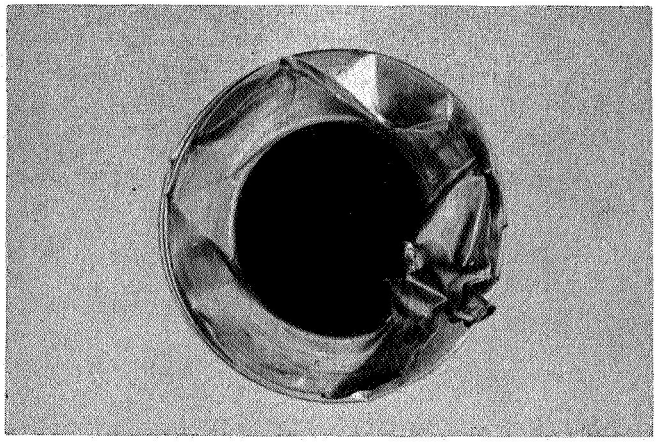

Fig. 5-End view of failed bellows. 4 X.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15

DATA: Macro Photographs of Bellows

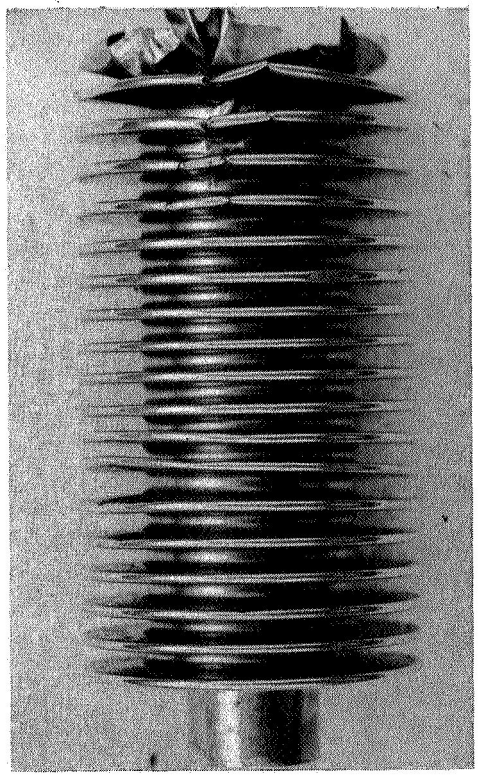

Fig. 6

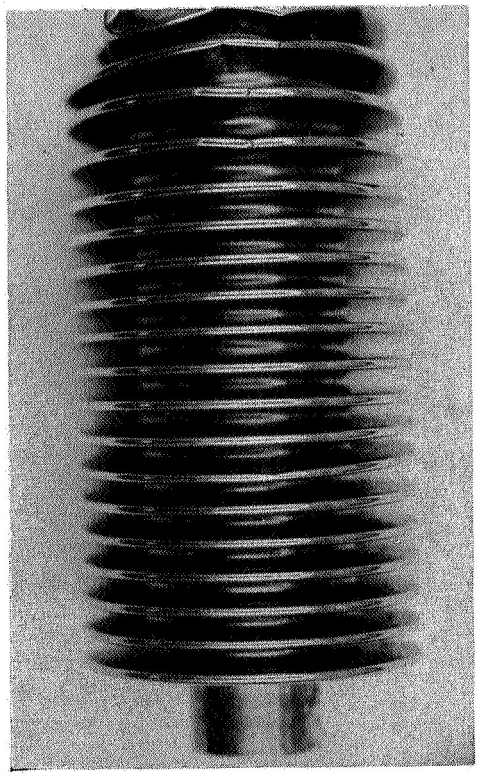

Fig. 7

Macro photographs of the failed bellows pointing up the crown cracks on both sides of bellows. 4X.

The failed bellows is shown in the "as received" condition.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15

DATA: Macro Photograph of Failed Bellows

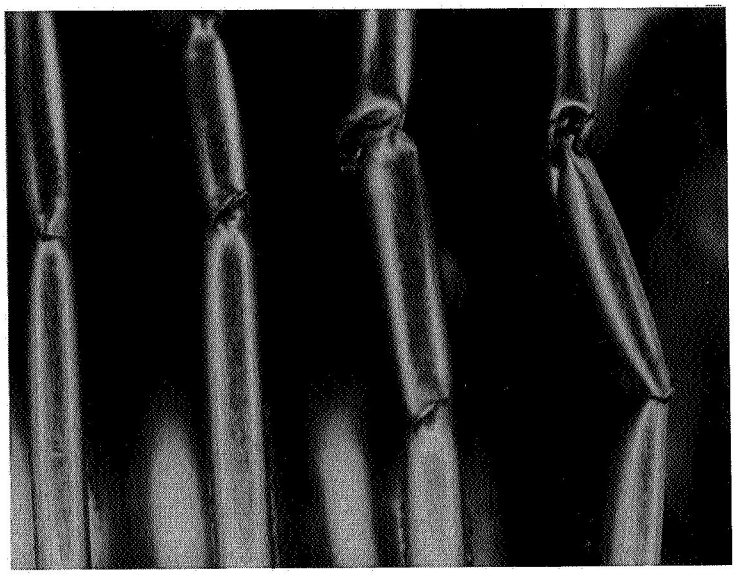

Fig. 8. 20 X.

Figure 8 shows the typical crown cracks and distortions found in the bellows in the "as received," condition. The area shown here can also be seen in Figure 6.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15
DATA: Metallographic			

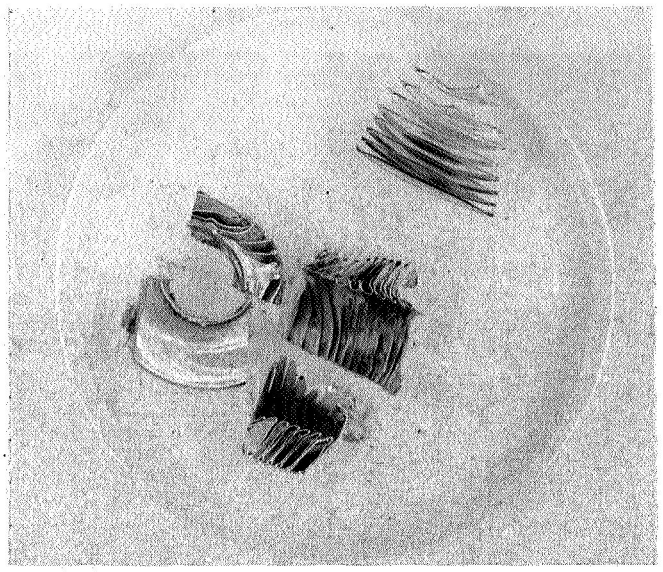

Fig. 9-Macro photograph of bellows sections as mounted in lucite prior to etching. 2.6 X.

Fig. 10-As polished cross section of bellows material showing pit on interior face of bellows. 1000 X.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15
DATA: Metallographic			

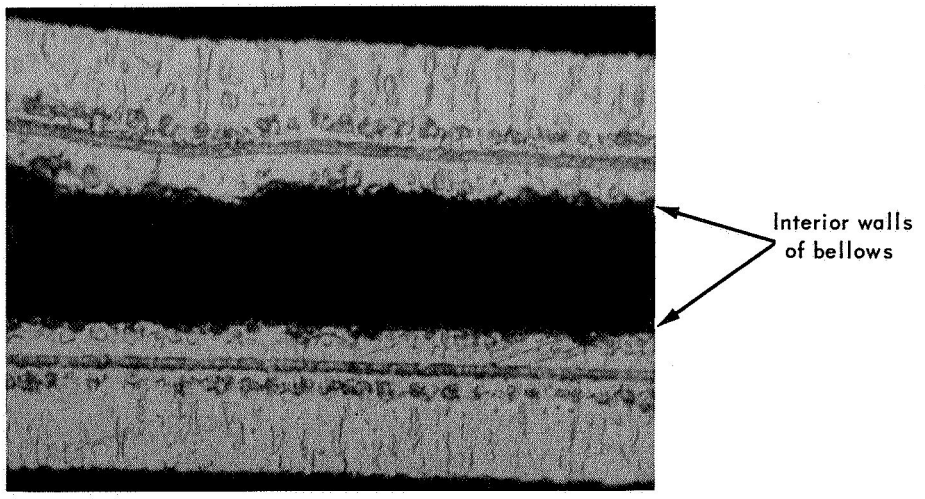

Fig. 11-Etch =50/50 HNO_3 and glacial acetic acids. 1000 X.

Figure 11 shows the typical columnar grain structure of the electrodeposited hi nickel Bellows material.

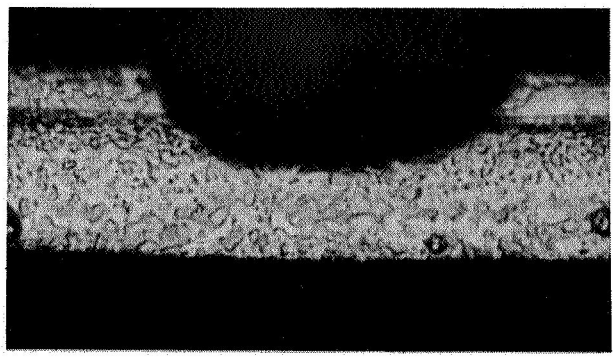

Fig. 12-Etch: same as above. 1000 X.

Figure 12 shows the same pitted area as is shown in figure 10. The microstructure is that of random grain growth rather than the typical columnar grains of figure 11.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15

DATA: Effect of Ruby Flux on Various Metals

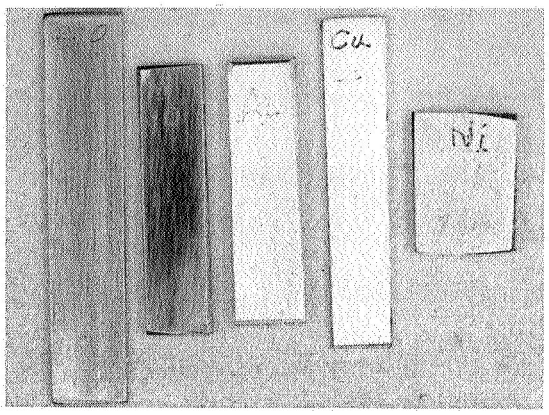

Fig. 13-Macro photograph at 1-1/2 diameters, showing the metal samples as prepared prior to exposure to the Ruby Flux.

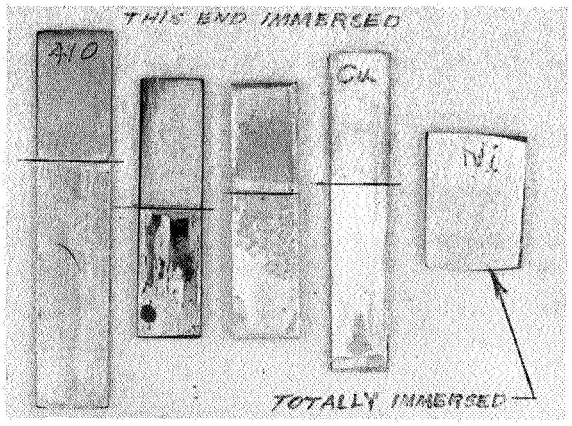

Fig. 14-Macro photograph at 1-1/2 diameters of the metal samples after 20 hours of partial immersion in the Ruby Flux.

In Figure 14, note the lack of attack on the non-immersed portion of the 410 stainless steel sample, and the totally immersed nickel sample. On the other three samples the evidence of corrosive attack is more apparent in those portions of the samples which were not actually in the solution, but were in the vapors.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15

DATA: Effect of Ruby Flux on Various Metals

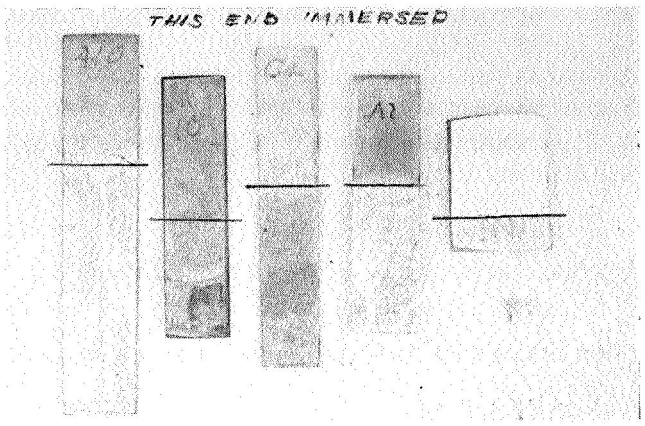

Fig. 15-Macro photograph at 1-1/2 diameters after total time of 44 hours of partial immersion in Ruby Flux. The note under Figure 14 is still applicable.

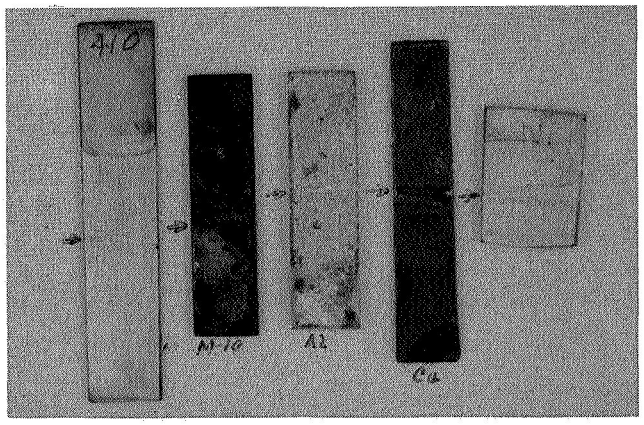

Fig. 16-Macro photo at 1-1/2 diameters after the foregoing exposure plus an additional 71 hours of exposure in the Ruby Flux vapors.

Severe corrosive attack was observed on all the metals tested.

Small arrow points to general location of area where the sample was held by a nylon thread for the final 71 hours of the test. During this phase of the test no part of any sample touched the flux solution.

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(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-17	673S69-01	1000-15
DATA: Excerpts from the Servometer Corporation Brochure #3M-1061, Titled, Miniature Metal Bellows			

1. "Material:

Bellows are supplied in one alloy only at present, a Nickel hardened by alloying with a small amount of other elements."-------"The material is corrosion resistant and will not rust or tarnish. It is unaffected by any alkalis and most mild water solutions, but is attacked by acids. It is not stainless."

2. "Fabrication:

These bellows solder easily with any flux suitable for copper."

Note on (2): Ruby flux is not suitable for copper since any residue may cause severe corrosion.

The Ph value of Ruby Flux is 4.5 which is acid.

W. G. Grenier 6-6-63
(Signature) *(Date)*

Sect. Head

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

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C. E. Vest	S-17	673S69-01	S.R. 1000-15

CONCLUSIONS:

The pit (photomicrograph #10) shows that the corrosion was internal. It is evident from photomacrographs 13, 14, 15 & 16 that the Ruby Flux does corrode nickel and copper. The literature on the bellows states that the material is not corrosion resistant in acids. Ruby Flux is definitely acidic (p ^{H} 4.5).

From this analysis, it can be concluded that the bellows material failed due to pitting and stress corrosion caused by the incomplete removal of the Ruby Flux after soldering.

Charles E. Vest

(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C. E. Vest	6	S-204	S-51	634S67-01	1200-27

DATE IN	DATE COMPLETED	PERFORMED BY
9-3-62	9-18-62	W. G. Grenier

NAME OF TEST

Metallurgical Examination

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Pallet from S-51 escapement mechanism.

Material is 303 easy machining stainless steel

3 pieces:

A = Small fractioned tip with indentation in surface

B = Remainder of shaft from which A came.

C = A new, unused pallet

EQUIPMENT INVOLVED:

1. Kentron microhardness tester
2. Unitron Metallograph
3. Metallographic laboratory polishing apparatus
4. Chemical reagents to compose Marbles Etchant.

RESULTS:

1. See sheets 4 & 5, Sketches 1-4 incl. for microhardness impression locations
2. See sheet 6, Table 1, for Hardness Data.
3. The Originator has all photomacrographs and photomicrographs.

W. G. Grenier 9-18-62

(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-51	634S67-01	1200-27

PROCEDURE: It was desired to determine why a specific pallet failed when similar ones did not.

Three samples were submitted for metallurgical examination and microhardness determinations. The samples are defined on sheet-1 of this report and listed as Samples A, B, and C.

The specimens were mounted in separate lucite molds, such that their longitudinal axes would be parallel to the mold face. Sample A was a special case, therefore care was taken that it be mounted such that its longitudinal axis was parallel to the mold face and the indentation normal to the mold face plane. Each specimen was ground to a distance of a few thousandths of an inch below its surface. In the case of sample A, grinding was then stopped for the purpose of preliminary study. In the cases of samples B and C, grinding continued to within approximately 0.005 of their respective axis. They were then polished to the depth of their respective axes.

The specimens were polished through the lapping wheels and photomicrographs of samples A and B were prepared at 65X, in the as polished condition. These showed the large numbers of inclusions inherent in the material, as well as the severe indentation and diagonally opposite, oversize radius of Sample A. Further, a distinct undercut at one of the fillets was shown on Sample B. Samples A and B were repolished and etched, using Marbles etchant. Photomicrographs showing the cold work and inclusions were prepared at 65X. Sample A was observed at 1000 magnifications and a microfissure observed, eminating from an inclusion near the fracture point. Photomicrographs, of

W. G. Grenier 9-18-62
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-51	634S67-01	1200-27

PROCEDURE:

the Polaroid type were delivered to the Originator for his analysis and conclusions.

Microhardness data was obtained on the three samples in the locations shown in sketches 1 & 4 of the data. In the case of Sample A, data was initially obtained at a level slightly beneath the original surface of the specimen and again in a plane containing the longitudinal axis. The reading locations are shown in sketches 1 and 4. In the cases of Samples B and C, all microhardness data shows conditions in the plane of the samples axes. Reading locations are shown in sketches 2 and 3.

The microhardness data, presented in Table 1, was obtained using the Kentron Microhardness tester, with a 500 gram load and a 20X objective.

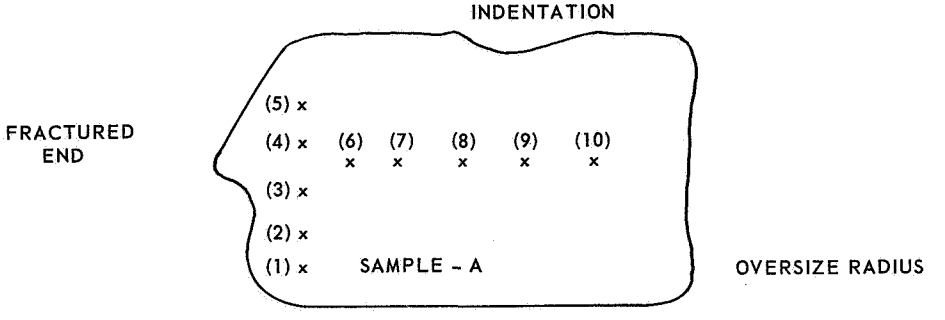
W. G. Grenier 9-18-62
(Signature) *(Date)*

SERVICE REPORT

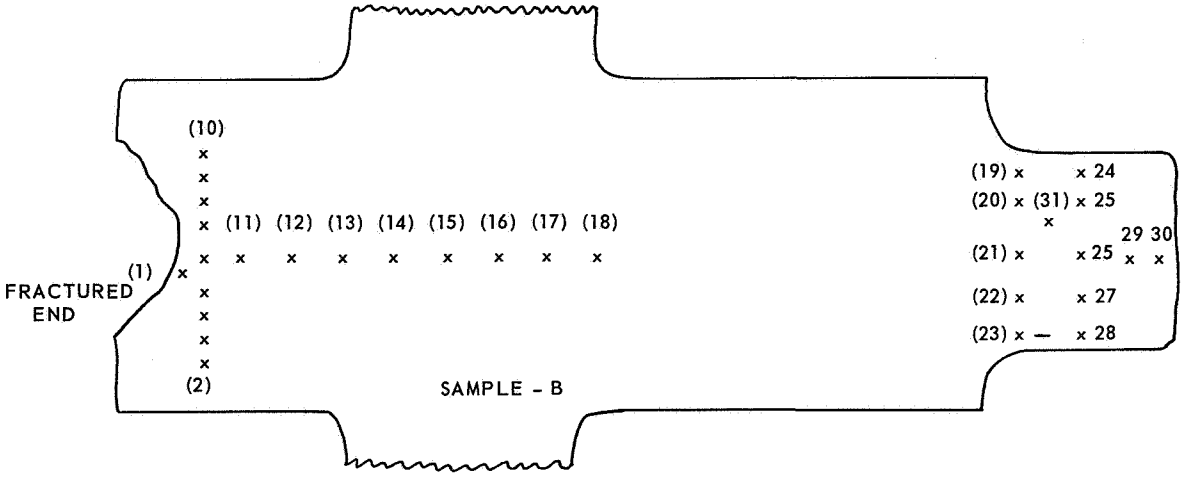
STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-51	634S67-01	1200-27

DATA: Microhardness Impression Locations



SK-1, shows 1st microhardness reading locations with specimen polished to a few thousandths of an inch below its surface. Readings 1 - 5 are 0.005 inches apart. Readings 6 - 10 are 0.010 inches apart.



SK-2, shows microhardness reading locations on Sample B, in axis plane. Readings 1 - 10 are 0.005" apart. Readings 11 - 18 are 0.010" apart. Readings 19 - 30 are 0.010" apart.

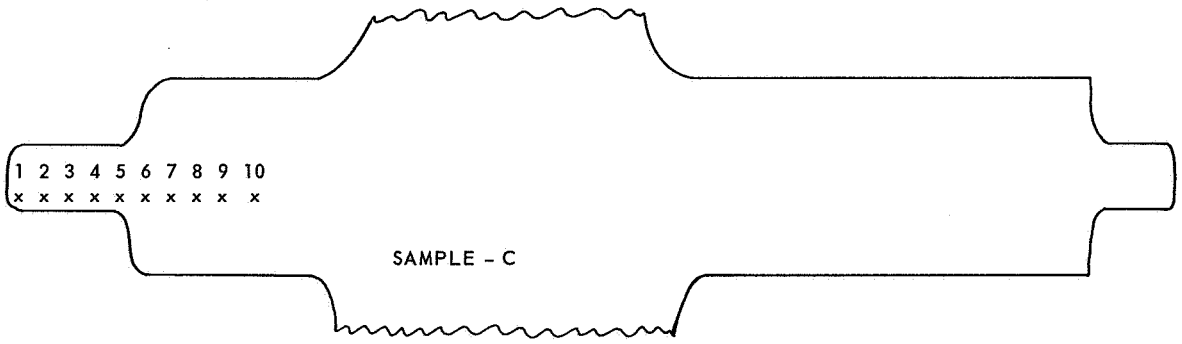
W. G. Grenier 9-18-62
(Signature) *(Date)*

SERVICE REPORT

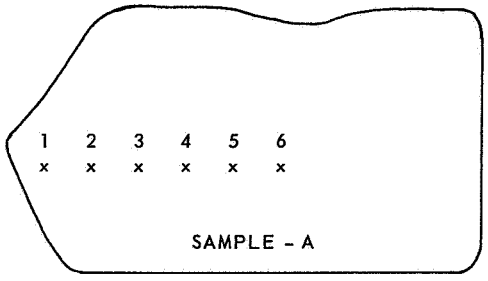
STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-51	634S67-01	1200-27

DATA: Microhardness Impression Locations



SK-3, shows microhardness reading locations on Sample C, in axis plane. Readings are 0.010" apart.



Sk-4, shows microhardness reading locations on repolished Sample A, in axis plane. Readings are 0.010" apart.

W. G. Grenier 9-18-62
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-51	634S67-01	1200-27

DATA: Microhardness Tests, Table-1

Sample	Sketch	Reading No.	D.P.H.N.	Conversion to R/C	Sample	Sketch	Reading No.	D.P.H.N.	Conversion to R/C
A	SK-1	1	330	34.3	B	SK-2	13	268.1	26.7
		2	335.2	34.8			14	268.1	26.7
		3	340.3	35.1			15	263.6	26.1
		4	346.9	35.8			16	263.6	26.1
		5	340.3	35.1			17	263.6	26.1
		6	298.8	31.3			18	271.8	28.3
		7	289.3	30.3			19	293.5	30.7
		8	271.8	28.3			20	284.3	29.5
		9	284.3	29.5			21	280.4	29.2
A	SK-1	10	280.4	29.2			22	284.3	29.5
							23	289.3	30.3
A	SK-4	1	335.2	34.8			24	319.0	33.2
		2	308.7	32.4			25	340.3	35.1
		3	271.8	28.3			26	330.0	34.3
		4	276.5	28.7			27	308.7	32.4
		5	268.1	26.7			28	323.9	33.8
A	SK-4	6	276.5	28.7			29	293.5	30.7
							30	298.8	31.3
B	SK-2	1	276.5	28.6	B	SK-2	31	284.3	29.5
		2	263.6	26.1					
		3	268.1	26.7	C	SK-3	1	271.8	28.3
		4	276.5	28.7			2	276.5	28.7
		5	271.8	28.3			3	280.4	29.2
		6	276.5	28.7			4	276.5	28.7
		7	276.5	28.7			5	276.5	28.7
		8	268.1	26.7			6	276.5	28.7
		9	259.2	25.5			7	280.4	29.2
		10	276.5	28.7			8	271.8	28.3
		11	280.4	29.2			9	271.8	28.3
B	SK-2	12	268.1	26.7	C	SK-3	10	263.6	26.1

W. G. Grenier 9-18-62
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	S-51	634S67-01	1200-27

CONCLUSIONS: Examination of the samples and microphotographs shows that the pallet failed in fatigue, caused by a bending moment, impact reversals, and stress concentration (insufficient fillet and undercut). It is also concluded that this failure was a rare occurence.

It is recommended that this type material (303 SS) not be used where stress concentration cannot be designed out of the product.

See memo Vest to H. E. Evans entitled "Metallurgicial Examination of a Fractured Pallet on the Escapement Mechanism." Dated 9-21-62

C. E. Vest
(Signature) *(Date)*

September 21, 1962

MEMORANDUM

TO: H. E. Evans

FROM: C. E. Vest

SUBJECT: Metallurgical Examination of a Fractured Pallet on the Escapement Mechanism S-51

REF: Test Request No. 1200-27

During winding of the cord onto the pulley on the escapement mechanism, the subject pallet failed. A new pallet was installed and attempts to cause failure were not satisfactory. The broken pallet was submitted to the Metallurgical Laboratory for metallurgical examination of the failure.

Discussions with Mr. Ton Eng and others revealed the following known facts:

1. The mechanism went through a calibration run (3 runs). Approximately 756 reversals per run or 2268 reversals.

2. The winding operation at time of failure was not completed (500 reversals).

3. Total known reversals 2800.

4. The pallet failed at the transition point of the small diameter to the larger diameter.

5. The fillet at this point was very small, practically non-existent, and the turned diameter rough.

6. The material is cold worked 303 stainless steel. This is an easy machining material with reduced yield strength due to the addition of P, S, or Se as the easy machining additive. These elements form non-metallic inclusions which are insoluble in the metal.

The pallet was observed at low power (10x to 50x) to determine macrostructure. This examination showed that the pallet had failed by fatigue. Points of nucleation are shown in Figure 1. The macrostructure also shows that the failure occurred instantly and was not a progressive failure. This instant failure is typical of fatigue failure. Figure 2 shows the mating end of the failure. Figure 3 shows the indented area on the small diameter where the pallet did not fit up close to the bearing, thereby creating a bending moment.

The specimen was next mounted in lucite for preparation for high magnification metallographic examination. Figure 4 shows the small diameter shaft unetched. Note the indented area on the diameter and the larger chamber at the opposite corner of the shaft. Also note the elongated non-metallic inclusions typical of 303 SS.

The specimen was etched and Figure 5 and 6 show the micro structure. The absence of a complete anneal is shown by the directionality of the grains and the present of cold worked grains (dark grains). A close examination at 1000x revealed a micro crack adjacent to the failure which is frequently found in this area. The mating part of the failure was examined and Figure 7 shows undercut at the fillet and the non-metallic inclusions typical of 303 SS. Figure 8 shows the directionality of the grains and the absence of complete annealing.

Micro hardness measurements were made on the specimen and significantly harder band ($5R_c$ harder) was found in the general area of the transition point (large OD to small OD) and fractured point. This is probably a contributing factor to the fatigue failure.

An untested pallet was sectioned, the microstructure examined and compared to the fractured specimen. The microstructure was very similar (cold worked grains and inclusions), and the hardness comparable ($29R_c$ vs $28R_c$); the fillets at the transition point are insufficient and would probably produce a stress concentration and there are no hardness bands.

Figures 9, 10,and 11 show the position of the hardness measurements and their relative position to the fracture and transition point in the fractured pallet.

Figure 12 shows the pallet assembled in the mechanism. Note that the pallet is not centered over the adjacent gear and that the small diameter shaft (area of failure) does not fit up against the shoulder of the frame.

From the above results and discussion, the following conclusions can be drawn:

1. The pallet failed in fatigue at a point of high stress concentration due to the combined effects of a bending moment (poor fit-up of small shaft into bushing), a stress concentration (lack of sufficient fillet), impact reversals (type of operation), the position of the band of harder material and the possibility of an inclusion or inclusions being in a position to initiate fatigue cracks.

2. As a failure did not happen in a second pallet after numerous reversals and the good pallet sectioned showed no deviations from a normal structure, it is postulated that this failure was a rare occurrence.

The following recommendation is pertinent to this type material. If a stress concentration may be present due to design limitations, 303 stainless steel should not be used as the material of construction and that 302 stainless steel be substituted in its place.

Charles E. Vest
ATD Section

Attachments

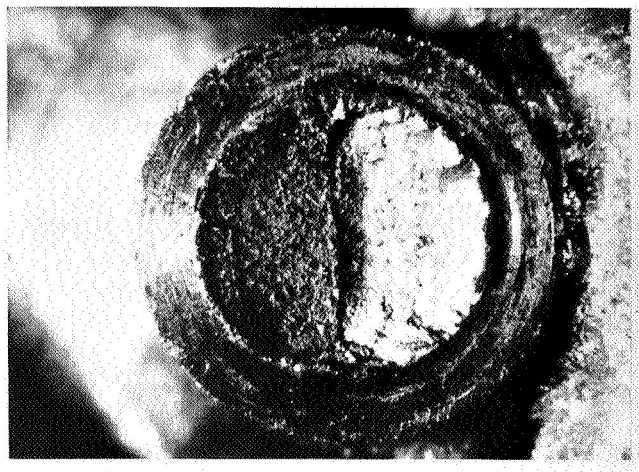


Figure 1. Photomacrograph showing failure (end view) and points of crack nucleation. 50x

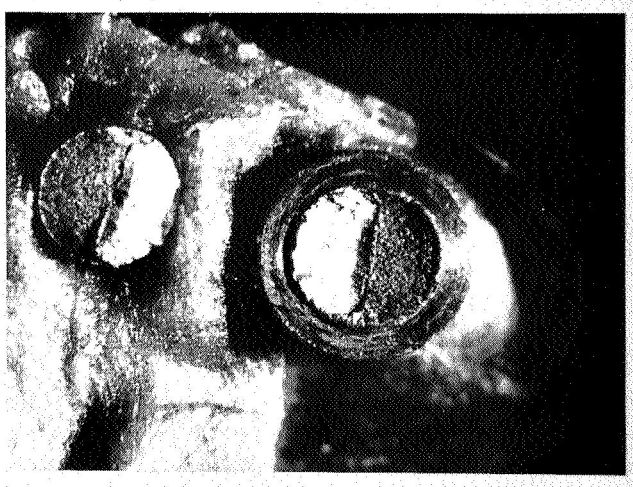


Figure 2. Photomacrograph showing mating ends of the fracture. 10x

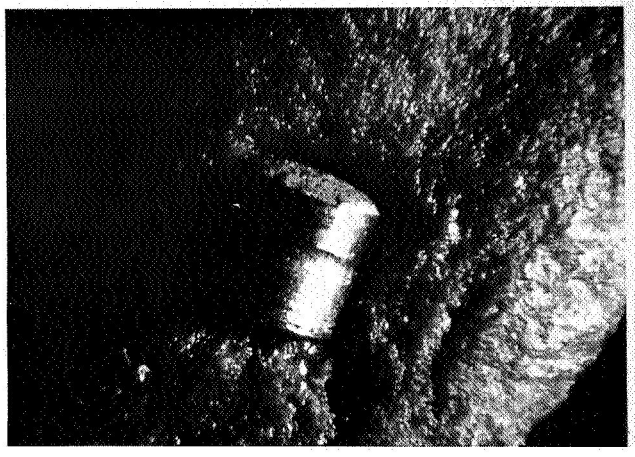


Figure 3. Photomacrograph showing indented area produced by impact reversals and misfit of shaft in bushing. 10x

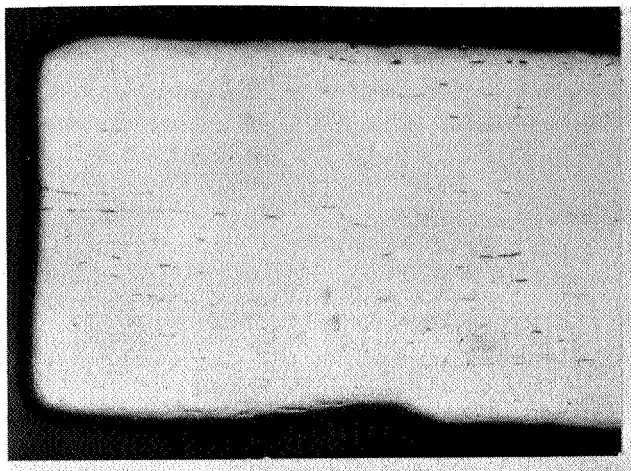


Figure 4. Photomicrograph showing elongated inclusions, indented area and enlarged chamber. 65x, unetched.

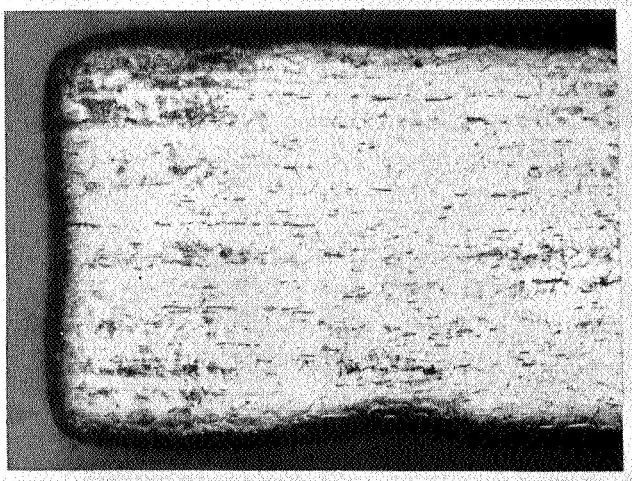


Figure 5. Photomicrograph showing cold work. (dark grains and general elongated grains) 65x, etched.

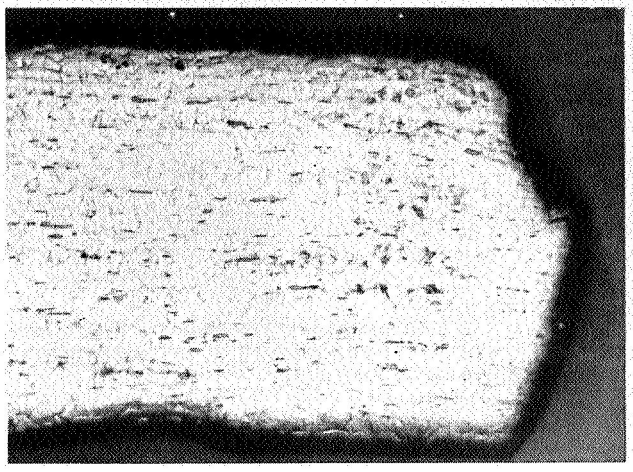


Figure 6. Photomicrograph showing fractured end of specimen, cold work, and inclusions. 65x, etched

Figure 7. Photomicrograph showing inclusion and undercut at fillet (stress concentration). 65x, unetched.

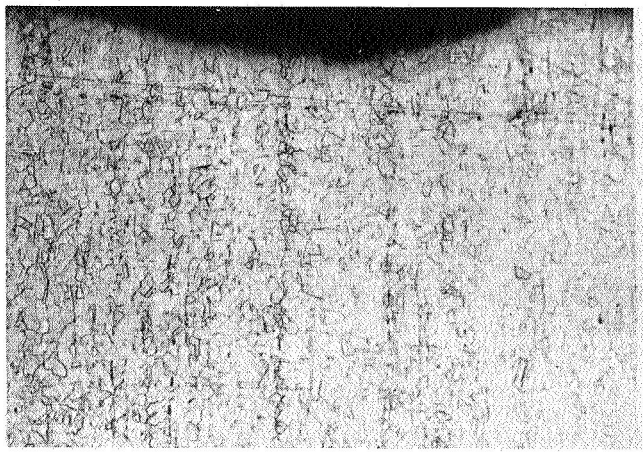


Figure 8. Photomicrograph showing presence cold work, directionality of grains at the fracture. 65 x, unetched.

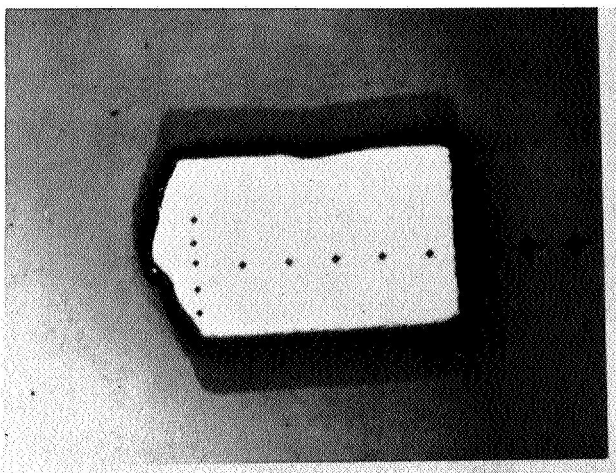


Figure 9. Photomacrograph showing location of hard band at fracture. The transverse readings average 35Rc and the longitudinal bands average 29Rc. 27x, unetched.

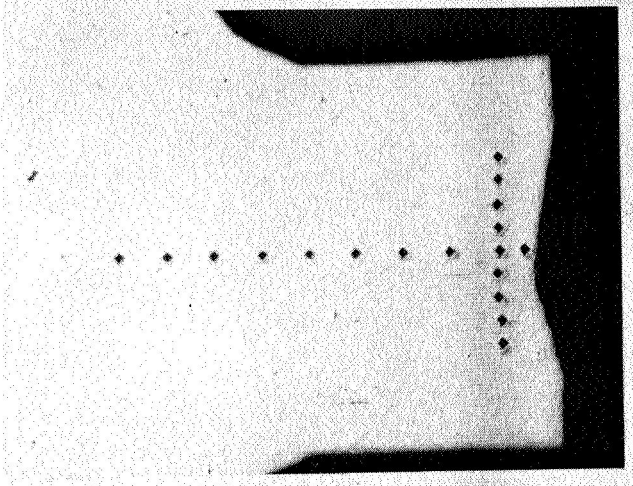


Figure 10. Photomacrograph showing opposite side of fracture than Figure 9 and shows no difference in hardness between transverse and longitudinal direction. 27x, unetched.

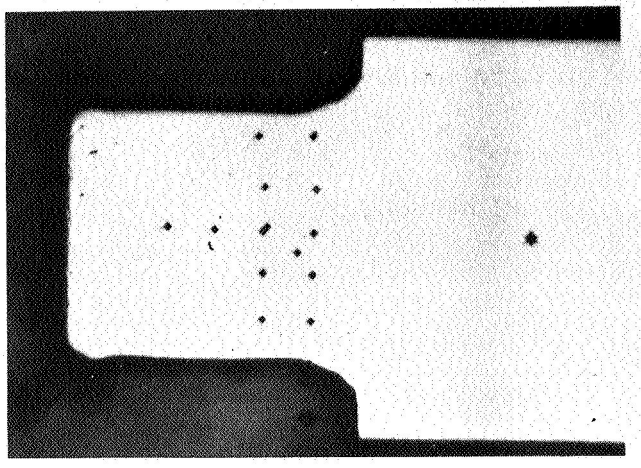


Figure 11. Photomacrograph showing small diameter shaft at opposite end of pallet. The transverse hardness readings closest to end of shaft average 34 Rc and the other transverse and longitudinal readings average 29 Rc. 27x, unetched.

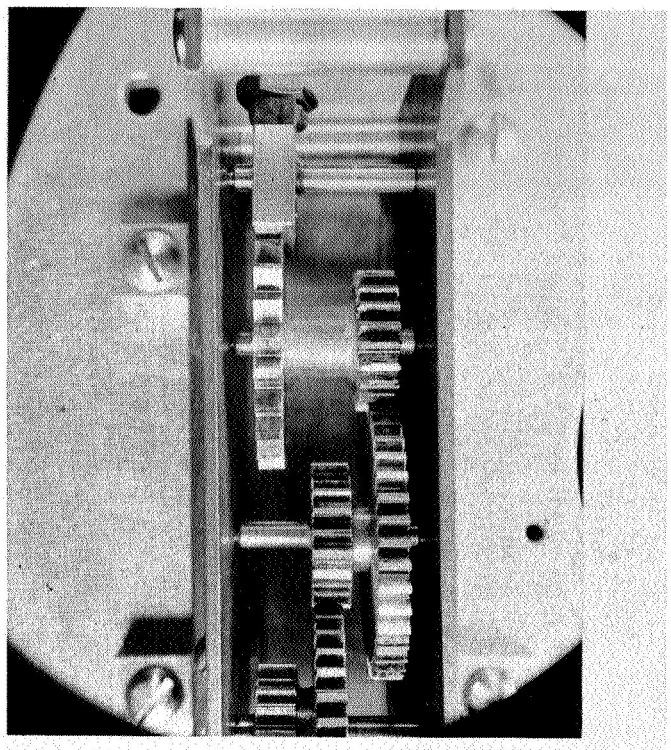


Figure 12. Photomacrograph showing overall view of pallet assembled into mechanism. Note fit up of small diameter in bushing (upper left). Also note possible offset of centerline of pallet with mating gear.

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C. E. Vest	Beltsville		OGO	673S70-01	1200-42

DATE IN	DATE COMPLETED	PERFORMED BY
8 April 63	11 April 63	Kauffman, Sween, Rocher

NAME OF TEST

Determine Change in Mechanical Properties and Microstructure of 2024T4, 6061T6, 7075T6 Aluminum Alloys subjected to a Heat Treatment of 6 hours at 315°F and cold water quench

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Perform tensile test of 8 samples of each alloy.

EQUIPMENT INVOLVED:

1) Tinius Olsen Electromatic Universal Tester
2) 30,000 lb Grips 'K'
3) Electric extensiometer No. S-100-1 (1" gage length)
4) 1" micrometer

NOTE: In all cases it took longer than 2 min. to break spec.

RESULTS:

J.H. Kauffman 12 Apr 63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

PROCEDURE:

1) Measure samples (cross sectional area) and record

2) Install sample in 'K' grips on T. O. Universal Tester

3) Install S-100-1 extensiometer on sample (strain in inches/inch)

4) Select load rate (inches/minute on cross head) 0.1"/min

5) Set chart to zero and record sample No., Range and rate

6) Perform test

J. H. Kauffman 11 Apr 63

(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA:

Spec. No.	Inches Width	Inches Thickness	Cross Sect. Area.
*61-1	.503	.1890	0.0951 in^2
*61-2	.503	.1895	0.0953 in^2
*61-3	.5035	.1890	0.0952 in^2
*61-4	.5015	.1890	0.0948 in^2
61-5	.503	.1890	0.0951 in^2
61-6	.5015	.1895	0.0950 in^2
61-7	.502	.1890	0.0951 in^2
61-8	.5015	.1890	0.0948 in^2
*24-1	.503	.1870	0.0941 in^2
*24-2	.503	.1870	0.0941 in^2
*24-3	.503	.1875	0.0943 in^2
*24-4	.5035	.1870	0.0942 in^2
24-5	.5035	.1870	0.0942 in^2
24-6	.5025	.1870	0.0942 in^2
24-7	.503	.1870	0.0941 in^2
24-8	.5025	.1875	0.0942 in^2
*75-1	.5065	.1905	0.0965 in^2
*75-2	.5063	.1845	0.0934 in^2
*75-3	.5055	.1845	0.0933 in^2
*75-4	.5057	.1929	0.0975 in^2
75-5	.5063	.1912	0.0968 in^2
75-6	.5063	.1841	0.0932 in^2
75-7	.5062	.1911	0.0967 in^2
75-7	.5056	.1900	0.0961 in^2

* These samples had special heat treatment. See Met. Lad Report.

J. H. Kauffman 11 Apr 63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA:

Spec. No.	Tinius Olsen Record			
	Ult. Strength Pounds	Yield Strength Pounds	Strain in/in	Load Rate (Cross Head)
61-1	—	—	—	—
61-2	3780	2760	0.200	0.02
61-3	3780	2700	0.200	0.01
61-4	3780	2760	0.198	0.01
61-5	3480	2220	0.200	0.05
61-6	3480	2220	0.199	0.01
61-7	3540	2160	0.198	
61-8	3480	2220	0.200	
24-1	6525	4275	0.193	
24-2	6600	4500	0.184	
24-3	6600	—	—	
24-4	6600	4500	0.206	
24-5	6825	4500	0.183	
24-6	6750	4500	0.184	
24-7	6825	4515	0.212	
24-8	6750	4500	0.202	
75-1	7650	6825	0.144	
75-2	7500	6725	0.120	
75-3	7425	6750	0.107	
75-4	7650	6900	0.116	
75-5	8025	7350	0.124	
75-6	7800	7200	0.144	
75-7	7925	7200	0.112	
75-8	7650	7050	0.108	

J. H. Kauffman 11 Apr 63
(Signature) *(Date)*

SERVICE REPORT

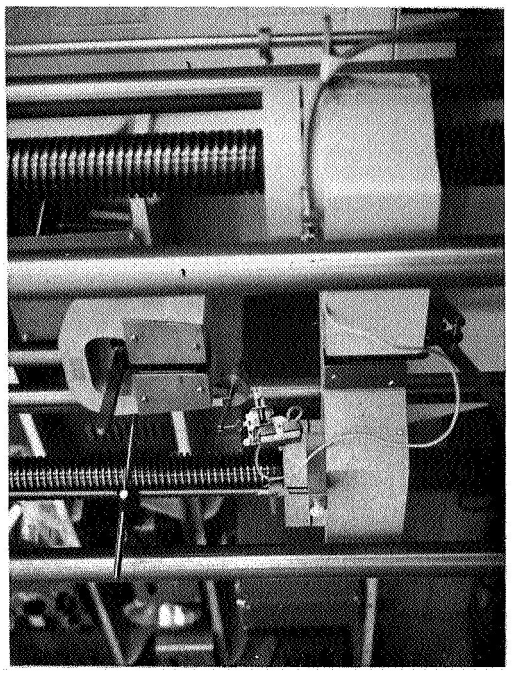
STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

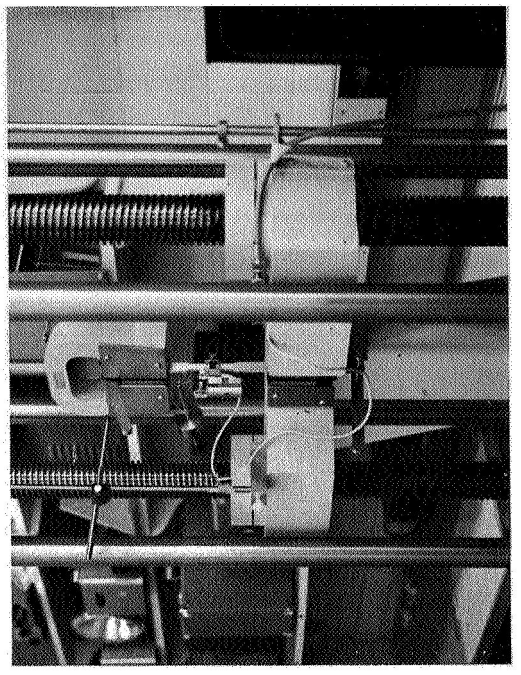
ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

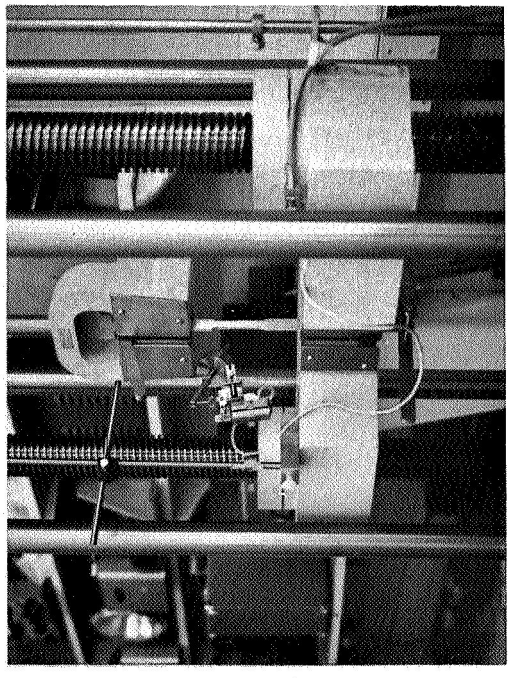
DATA:

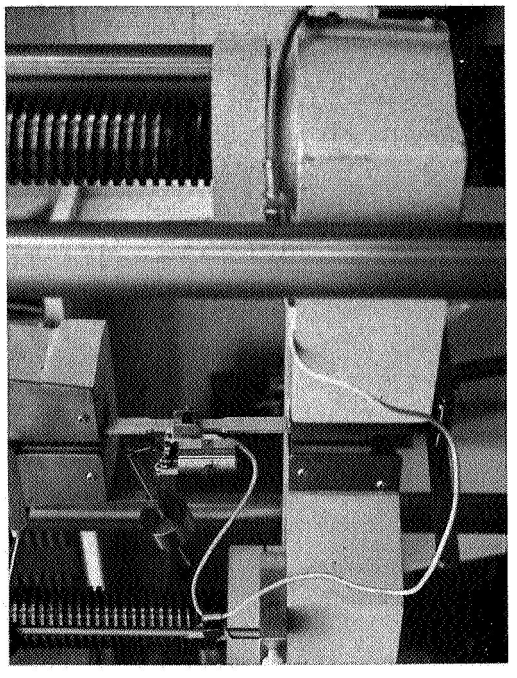
Spec. No.	Ult. Strength Psi	Yield Strength Psi
61-1		
2	39664	28961
3	39706	28361
4	39873	29114
5	36593	23344
6	36632	23363
7	37224	22713
8	36709	23418
24-1	69341	45430
2	70138	47822
3		
4	70064	47771
5	72452	47771
6	71656	47771
7	72529	47981
8	71656	47822
75-1	79275	70725
2	80300	72002
3	79582	72347
4	78462	70769
5	82901	75930
6	83691	77253
7	81955	74457
8	79605	73361

(Signature) *(Date)*









Test Equipment: Tinius-Olsen Testing Machine
Extensometer - S 100-1
Grips - 30,000 lb.

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C. E. Vest	Beltsville	125	OGO	673S70-01	T.R. 1200-42

DATE IN	DATE COMPLETED	PERFORMED BY
4-2-63	5-13-63	J. Wall and W. G. Grenier

NAME OF TEST

Determination of Changes in Mechanical and Physical Properties of Al Alloys

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Received: Eight (8) extra length 1/2" flat tensile test specimens purportedly of each of the following alloys of Al:

2024-T4, to be samples numbered 24-1 through 24-8
6061-T6, to be samples numbered 61-1 through 61-8
7075-T6, to be samples numbered 75-1 through 75-8

Specimens numbered 1-4 inc. of each alloy are to be heat treated at 315°F ± 15°F for 6 hours and water quenched prior to tensile tests. Metallurgical samples removed from each tensile specimen.

EQUIPMENT INVOLVED:

Heat treating furnace, Misc. hand tools, Buehler standard mounting press, transoptic mounting powder, belt sander, Buekler Handimet hand polishing apparatus, Fast and slow speed lapping wheels, automet polishing apparatus, 6μ diamond paste, Gamal Alumina, Variety of chemical reagents, Bausch and Lomb Model 'L' camera with 4" × 5" Polaroid camera attachment, Unitron Bench Microscope, Standard Rockwell Hardness Tester, Unitron Metallograph with Polaroid camera back.

RESULTS:

Heat treatment data — Sheet #7

Hardness data – Sheet #8

As polished photomicrographs – Sheets #9 - #11 inc.

Macrostructure of 2024 Al – Sheet #12

Microstructures of all alloys in all conditions – Sheets #13 - #16 inc.

Chemical composition of alloys – Sheet #17

W. G. Grenier 5-15-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

PROCEDURE: Received:

Eight (8) extra length 1/2" flat tensile test specimens, purportedly of each of the following alloys:

2024-T4, to be samples numbered 24-1 thru 24-8

6061-T6, to be samples numbered 61-1 thru 61-8

7075-T6, to be samples numbered 75-1 thru 75-8

Specimens numbered 1-4 inc. of each alloy received the following heat treatment prior to tensile tests:

Heat Treatment;

6 hours at 315°F ± 15°F = 157.2°C ± 8.3°C = 148.9°-1655°C

Quench in cold tap water.

Following heat treatment 1/4" to 1/2" was cut from one end of each of the twenty four (24) tensile test specimens for metallographic use. The tensile test specimens were given to Mr. J. H. Kauffman for mechanical tests. Each sample cut from a tensile specimen was labeled with the number born by the tensile specimen. One sample of each alloy, in each condition was then sectioned and labeled accordingly for Metallographic evaluation. Samples sectioned and mounted are: 24-1, 24-5, 61-1, 61-5, 75-1. 75-5. Each of these samples was sectioned and mounted such that one face in each of the transverse and longitudinal directions could be observed.

W. G. Grenier 5-14-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

PROCEDURE:

Sample Identification

Metallurgical Specimen Identification	Original mtl.	Lab. Condition	Plane of Specimen
24-1-T	2024-T4	Post heat treatment	Transverse
24-1-L	2023-T4	Post heat treatment	Longitudinal
24-5-T	2024-T4	As Received	Transverse
24-5-L	2024-T4	As Received	Longitudinal
61-1-T	6061-T6	Post heat treatment	Transverse
61-1-L	6061-T6	Post heat treatment	Longitudinal
61-5-T	6061-T6	As Received	Transverse
61-5-L	6061-T6	As Received	Longitudinal
75-1-T	7075-T6	Post heat treatment	Transverse
75-1-L	7075-T6	Post heat treatment	Longitudinal
75-5-T	7075-T6	As Received	Transverse
75-5-L	7075-T6	As Received	Longitudinal

Each transverse specimen was notched at time of final sectioning for simplification of identification.

Each of the foregoing specimens was; sectioned, mounted in lucite, rough ground on the belt surfacer, labeled, and polished through the papers by Mr. J. L. Wall. Employing the unmounted remains of each original sample, Mr. Wall performed standard Rockwell "B" hardness tests on the material.

W. G. Grenier 5-14-63
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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

PROCEDURE:

All specimens were polished, by hand, through the 1st wheel at slow speed with metcloth and 600 grit aluminum, and the slow wheel at slow speed with microcloth and Gamal Alumina. At this point the Originator viewed the specimens and suggested that photomicrographs be taken of each at four hundred diameters. Photomicrographs primary purpose, at this stage, is to point up the relative size and orientation of inclusions. Photomicrographs were obtained using the Unitron Metallograph.

The four 2024 Al specimens were etched by immersion in Kellers reagent as a test of the reagent, following the usual polish-etch, polish-etch routine. This produced an excellent macro etch, and Photomacrographs at twelve (12) diameters were prepared using the Bausch and Lomb Model 'L' camera.

After working with many different reagents and polishing techniques the following procedures produced satisfactory results.

Using vibrotool etcher, each hole of Automet specimen clamp was numbered from 1-5 inc. Specimens were placed in said clamp, noting location number, and orientated such that the lettering on the back of the specimen lay in lines tangent to the outer rim of the clamp. This facilitates the removal and replacement of any individual specimen.

All specimens were repolished, through the belt, papers, and 1st wheel. Final polishing and etch are as follows:

For 2024 and 7075 Al

1. Automet – 6μ diamond-silk cloth – 40# – 5 min.
2. Automet – Gamal-microcloth – 40# – 4 min.

W. G. Grenier 5-14-63
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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

PROCEDURE:

3. Etch – Kellers-hold in hand and swab – 6 sec.

4. Automet – Gamal-microcloth – 30# – 3 min.

5. Etch – as in 3. – 10 sec.

6. Automet – Gamal-microcloth – 30# – 2-1/2 min.

7. Etch – as in 3 – 15 sec.

8. Automet – Gamal-microcloth – < 30# – 2 min.

9. Etch – as in 3 – 20 sec.

Stopped here for 2024 Al, continued with 7075

10. Automet – Gamal-microcloth -<30# – 1-1/2 min.

11. Etch – as in 3 – 25 sec.

Stopped here for 7075 Al

Prepared photomicrographs of 7075 and 2024 Al

For 6061 Al

1. Automet – 6μ diamond-silk cloth – 40# – 5 min.

2. Etch – HF & HCl Soln-immerse and swab gently – 15 sec.

3. Automet – Gamal-microcloth – between 20# – 30# – 3 min.

4. Etch-as in 2. – 20 sec.

5. Automet – Gamal-microcloth – 20# – 2 min.

6. Etch-as in 2 – 30 sec.

7. Automet – Gamal-microcloth – 30#– 3 min.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

PROCEDURE:

8. Etch – as in 2 – 67 sec.

Stop.

Prepared photomicrographs of 6061 Al.

W. G. Grenier 5-15-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA: Heat Treatment Data for Tensile Test Specimens

Specimens Nos. 24-1, 24-2, 24-3, 24-4, 61-1, 61-2, 61-3, 61-4, 75-1, 75-2, 75-3, & 75-4.

Temperature range = 148.9°C - 165.5°C inc. = 300°F ± 15°F

Specimens placed in furnace 1015 hrs on 4-3-63.

Time	Temp. °C	Temp °F
1030	154	309
1100	152	306
1130	154	309
1200	155	311
1230	153	307
1300	155	311
1400	156	313
1500	154-1/2	310
1600	153	307
1630	154	309

Specimens were removed from the furnace at 1630 hours on 4-3-63 and quenched in cold water.

Temperature readings were taken, employing a cu-constantan thermocouple inserted through the back of the furnace.

W. G. Grenier 5-14-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA: Hardness Test Data, Rockwell "B"

Specimen No.	Hardness R/B	Condition
24-1	76	After 6 hour heat treatment
2	76	
3	77	
4	77	
5	78	As Received
6	78	
7	78	
8	78	
61-1	41	After 6 hour heat treatment
2	42	
3	41	
4	41	
5	26	As Received
6	26	
7	26	
8	26	
75-1	89	After 6 hour heat treatment
2	89	
3	89-1/2	
4	88	
5	91	As Received
6	90	
7	90	
8	89	

W. G. Grenier 5-14-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA: Photomicrographs, 2024 Al, 400 diameters, as polished.

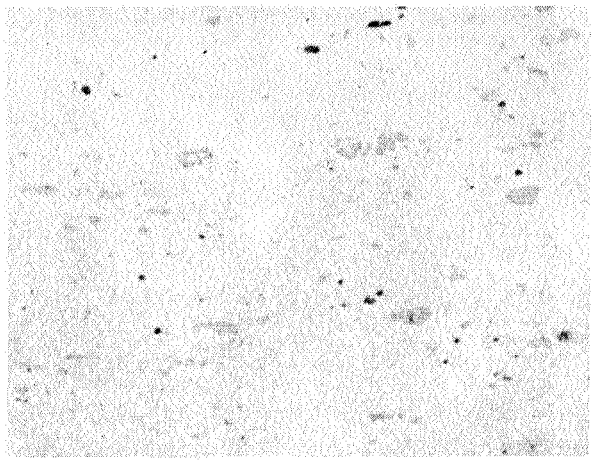

Figure 1-Before Heat Treatment

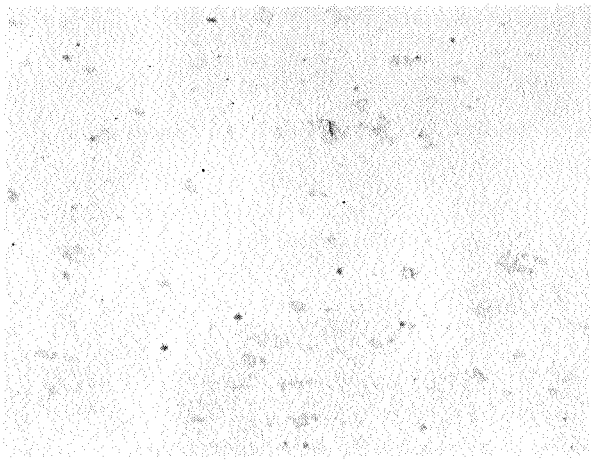

Figure 2-After Heat Treatment

2024 Al - Longitudinal Specimens

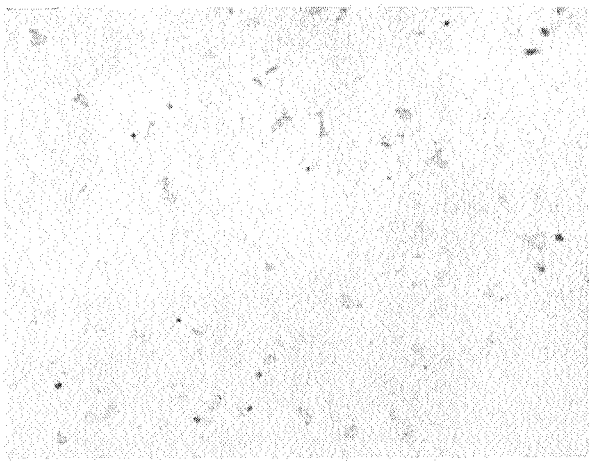

Figure 3-Before Heat Treatment

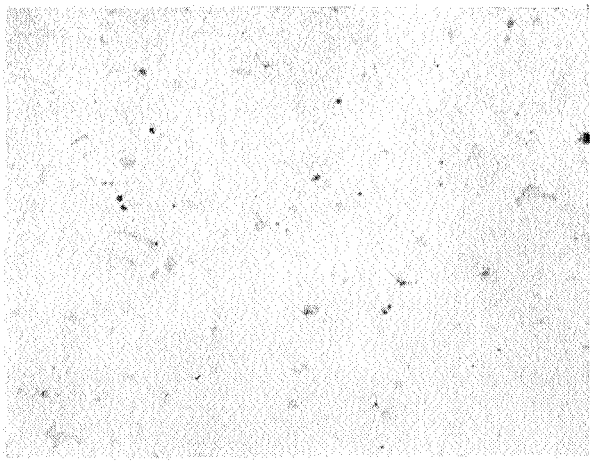

Figure 4-After Heat Treatment

2024 Al - Transverse Specimens

Note negligible apparent effect of Heat treatment.

W. G. Grenier 5-14-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA: Photomicrographs, 6061 Al, 400 diameters, as polished.

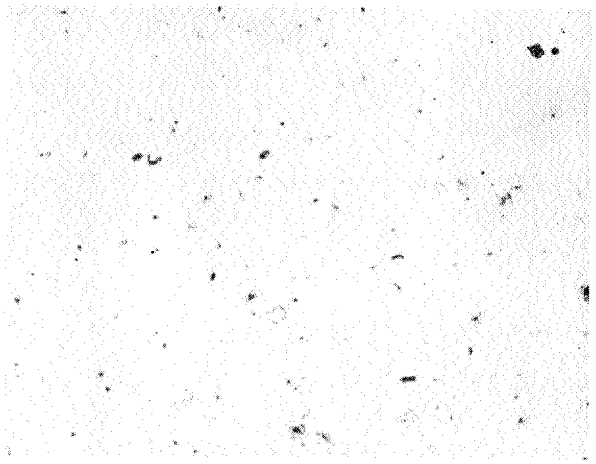

Figure 5-Before Heat Treatment

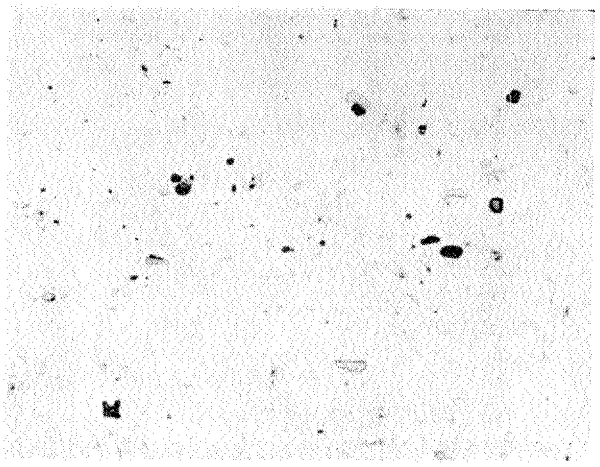

Figure 6-After Heat Treatment

6061 Al — Longitudinal Specimens

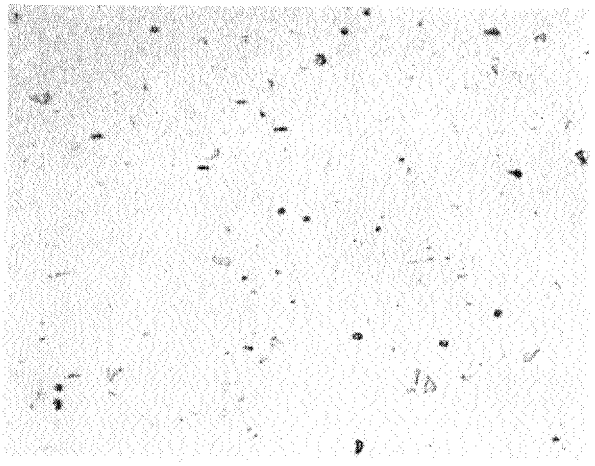

Figure 7-Before Heat Treatment

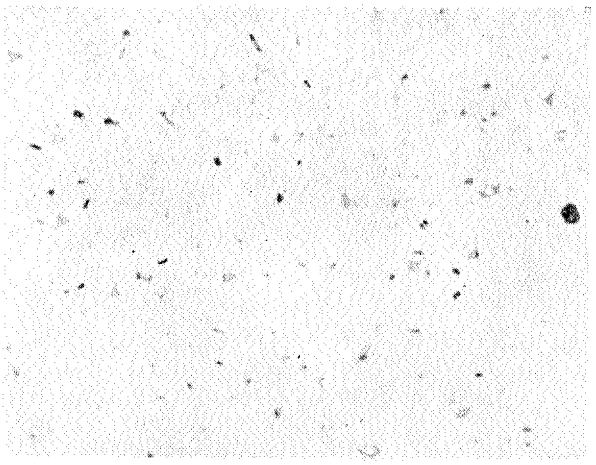

Figure 8-After Heat Treatment

6061 Al – Transverse Specimens

Note negligible apparent effect of Heat Treatment.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA: Photomicrographs, 7075 Al, 400 diameters, as polished.

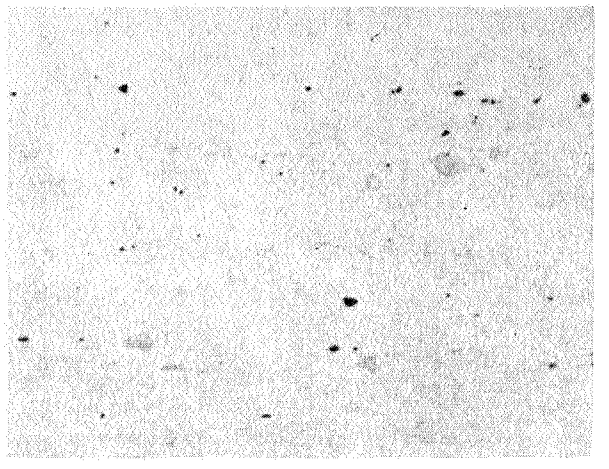

Figure 9-Before Heat Treatment

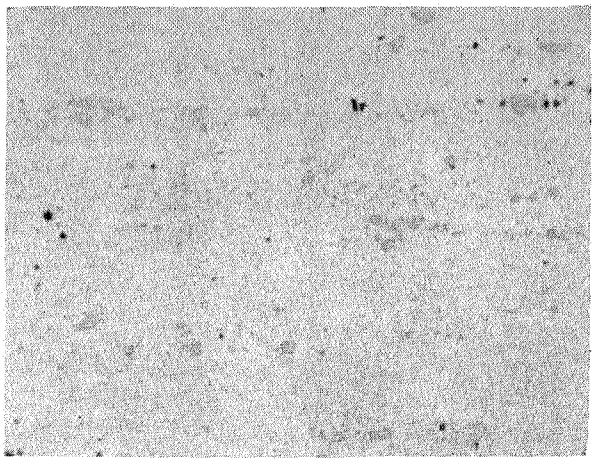

Figure 10-After Heat Treatment

7075 Al - Longitudinal Specimens

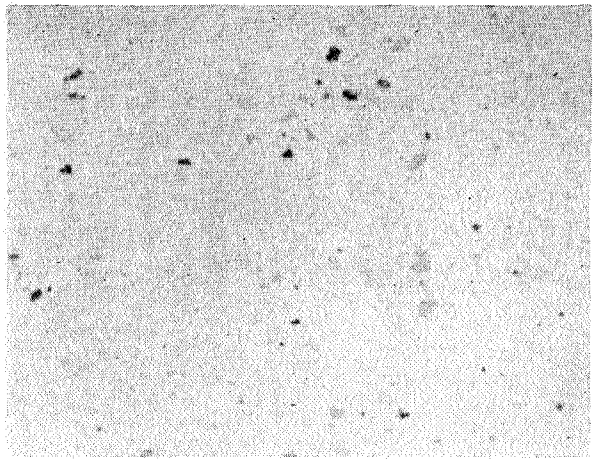

Figure 11-Before Heat Treatment

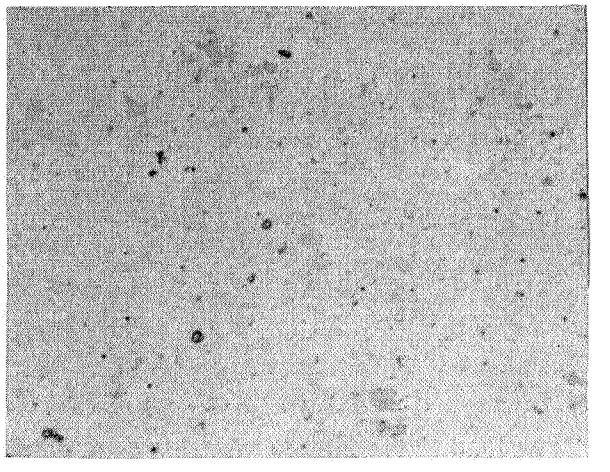

Figure 12-After Heat Treatment

7075 Al - Transverse Specimens

Note increase in inclusion density following Heat Treatment.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA: Photomacrographs, 2024 Al, 12 diameters, Kellers etch. by immersion.

Rolled edge

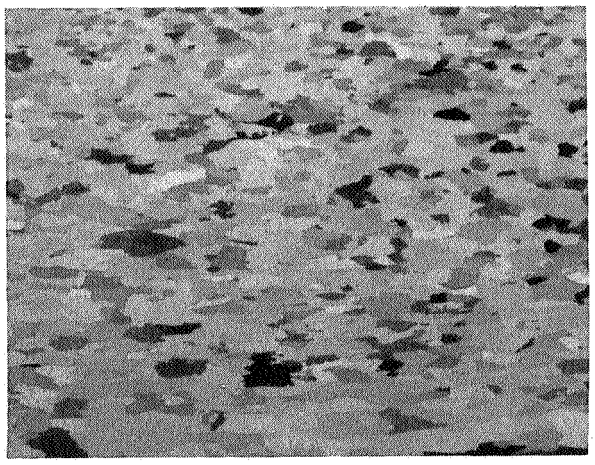

Figure 13-Before Heat Treat

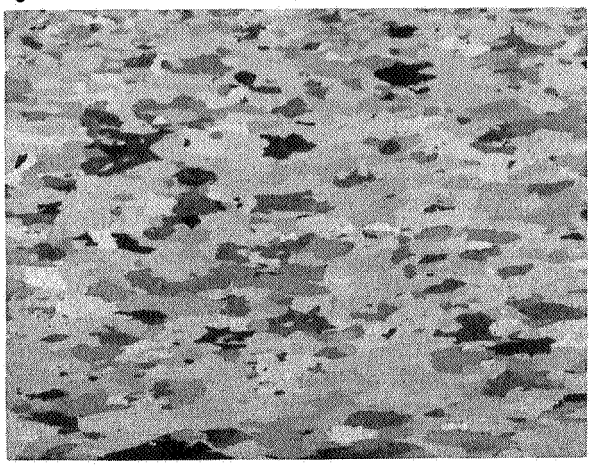

Figure 14-After Heat Treat

Longitudinal specimens in plane parallel to rolled surface.

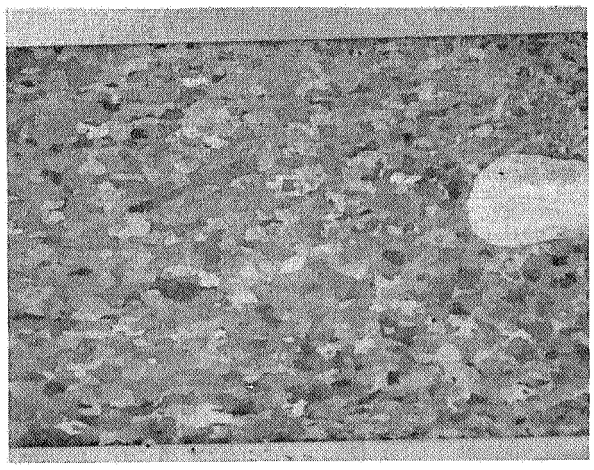

Figure 15-Before Heat Treat

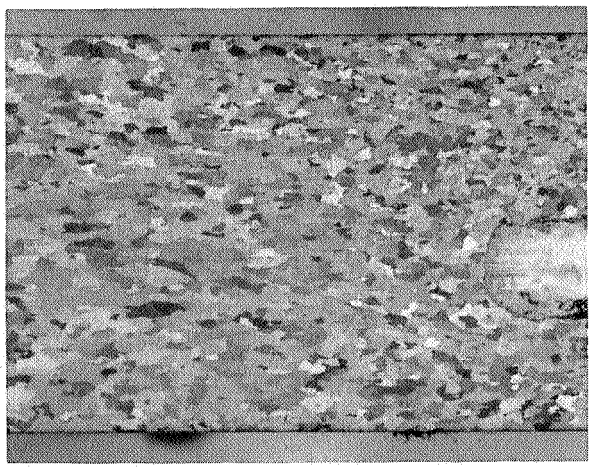

Figure 16-After Heat Treat

Transverse Specimens

Note grain growth in central portion of material.

W. G. Grenier 5-15-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA: Photomicrographs, 2024 Al, 100 diameters, Kellers etch. - see sheets #4, 5 & 6

Typical Microstructures

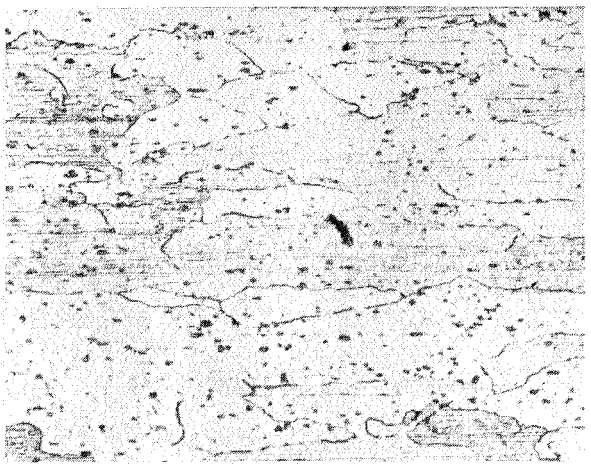

Figure 17-Preheat Treat

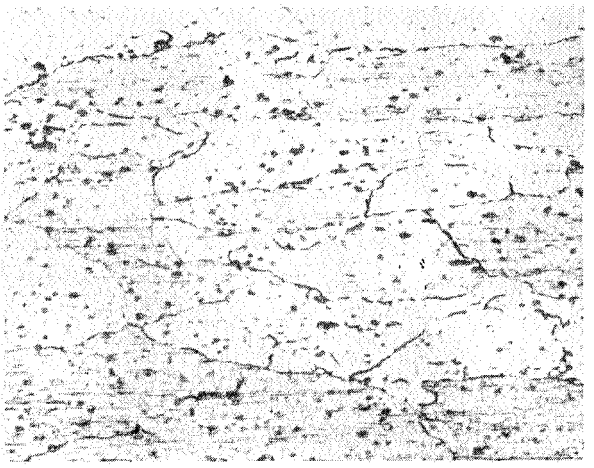

Figure 18-Postheat Treat

Longitudinal Specimens

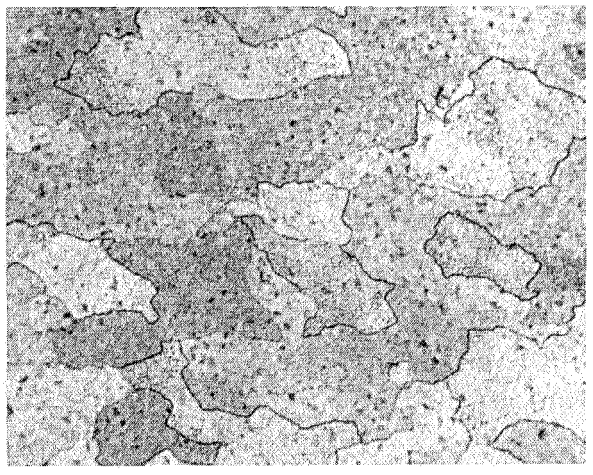

Figure 19-Preheat Treat

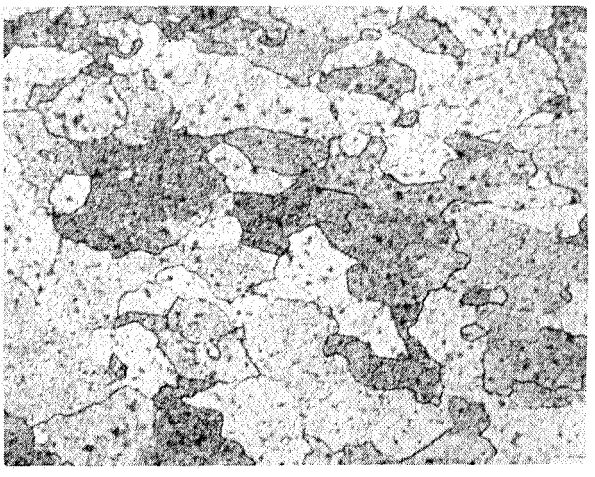

Figure 20-Postheat Treat

Transverse Specimens

Some grain refinement shows in heat treated specimens, with some increase in the precipitates.

W. G. Grenier 5-15-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA: Longitudinal 100 and 200 diameters, as designated, Photomicrographs, 6061 Al: Etchant - HCl & HF, see pgs. 4, 5 & 6

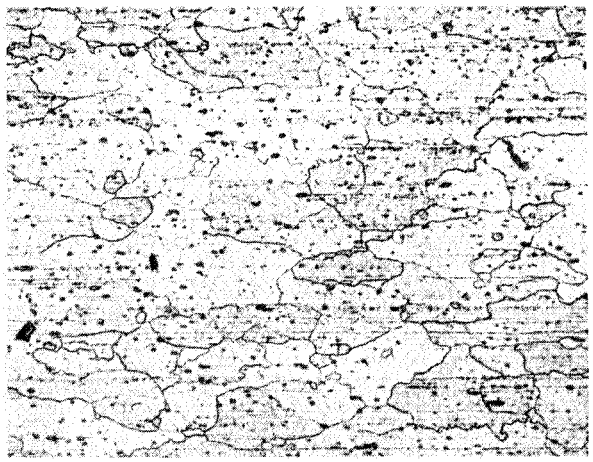

Figure 21 100 X

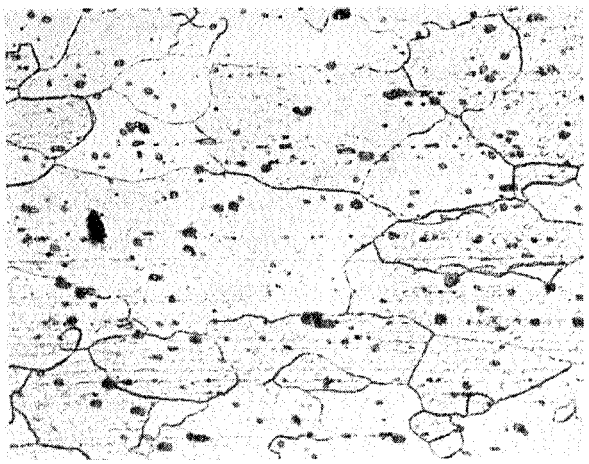

Figure 22 200 X

Preheat Treatment - Longitudinal Specimen

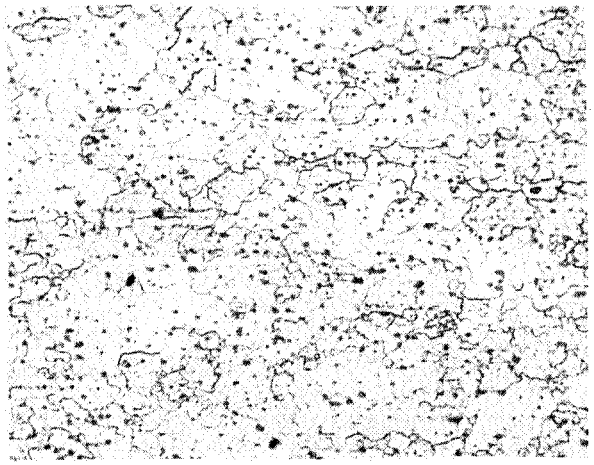

Figure 23 100 X

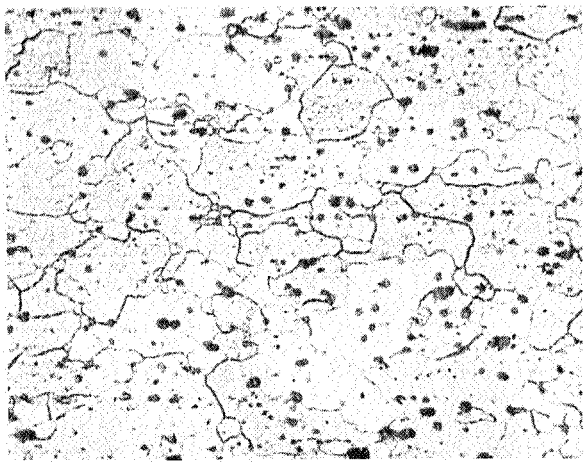

Figure 24 200 X

Postheat Treatment - Longitudinal Specimen

Note grain refinement and increase in intermetallic compound precipitates in heat treated specimen.

W. G. Grenier 5-15-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA: Photomicrographs, Transverse, 6061 Al, 100 and 200 diameters, as designated, Etchant - HCl & HF, see pgs. 4, 5 & 6

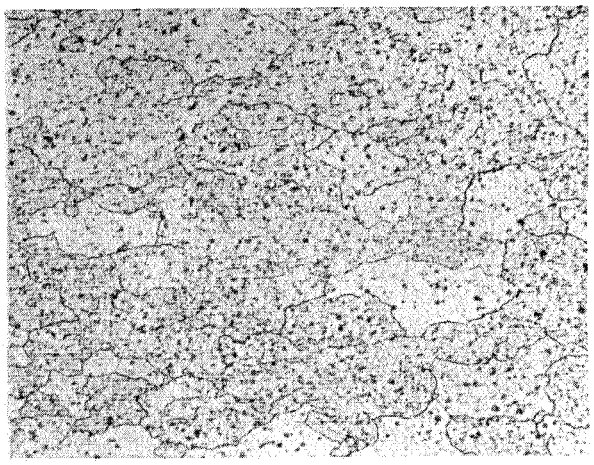

Figure 25 100 X

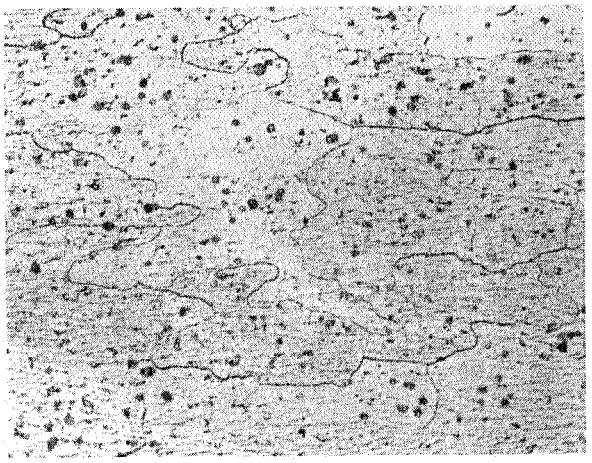

Figure 26 200 X

Preheat Treatment specimen

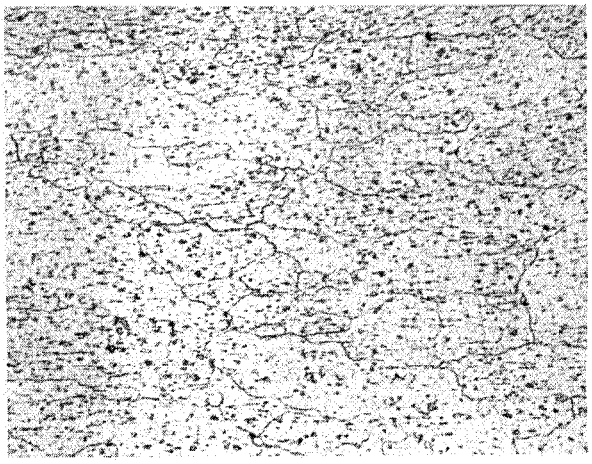

Figure 27 100 X

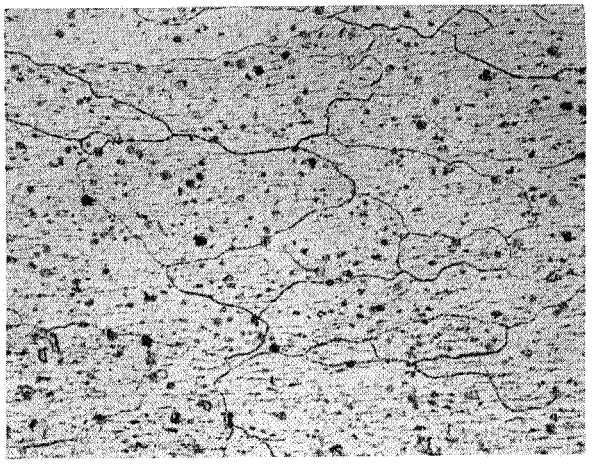

Figure 28 200 X

Postheat Treatment Specimen

See note on preceeding page.

W. G. Grenier 5-15-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA: Photomicrographs, 7075 Al, 100 diameters, Kellers Etch. - see pg. 4

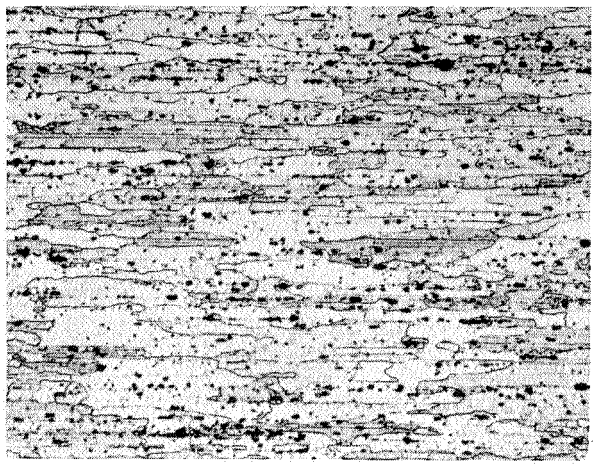

Figure 29-Preheat Treat

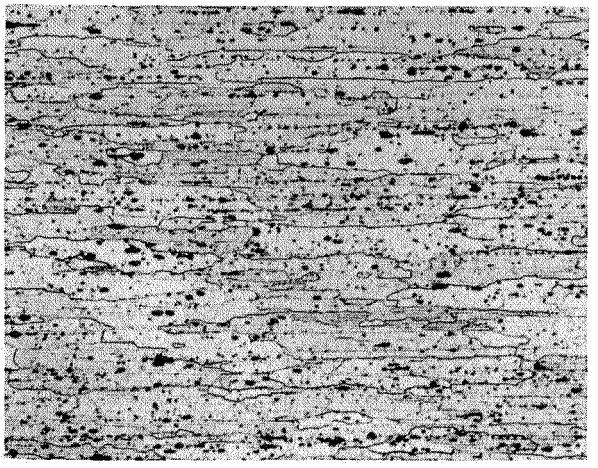

Figure 30-Postheat Treat

Longitudinal Specimens

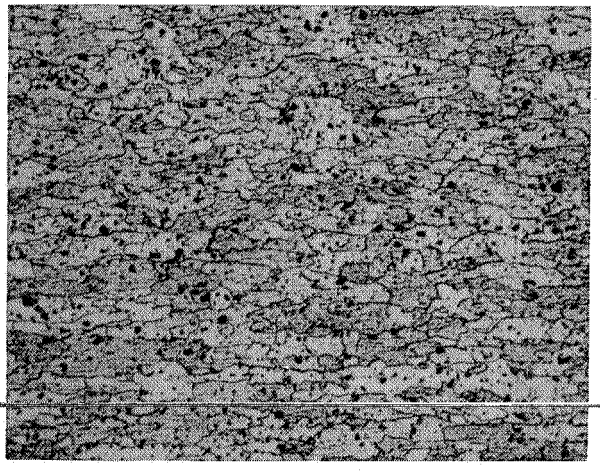

Figure 31-Preheat Treat

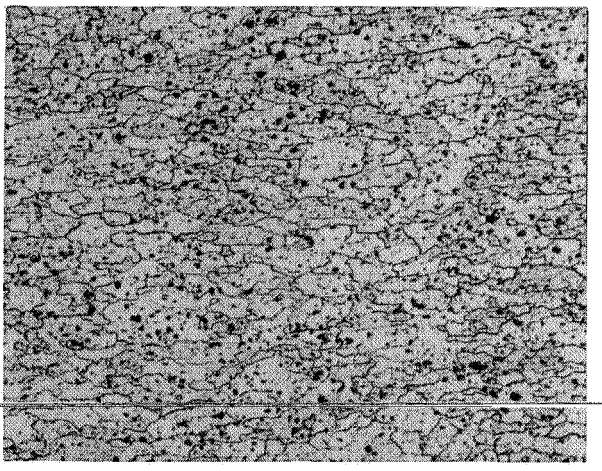

Figure 32-Postheat Treat

Transverse Specimens

Figures 29-32 show no obvious change in microstructure due to heat treatment.

W. G. Grenier 5-15-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO	673S70-01	1200-42

DATA: Chemical Constituents of Alloys

Basic Alloying Ingredients — Nominal Percent

Type of Al	2024	6061	7075
Alloy	%	%	%
Fe	0.5	0.7	0.7
Si	0.5	0.6	0.5
Cu	4.5	0.25	1.6
Mg	1.5	1.0	2.5
Mn	0.6	—	—
Cr	—	0.25	0.3
Zn	—	—	5.6
Ti	—	0.15	0.2

W. G. Grenier, 5-15-63
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO (MoS_2)	673S-70-01	1200-42

CONCLUSIONS: Summary of the Mechanical Properties of the three Materials

	2024-T4	6061-T6	7075-T6
As received			
Yield St.	48,000	23,200	71,400
Ult. Tensile St.	75,000	36,700	79,000
Hardness BHN	141	65	157
Hardness R_b	78	26	90
After Heat Treatment			
Yield St.	44,000	28,800	75,200
Ult. Tensile St.	70,000	39,700	82,000
Hardness BHN	137	87	152
Hardness R_b	76	41	89
Average Typical values of As Received Condition as referenced in Metals Handbook - ASM			
Yield St.	47,000	49,000	73,000
Ult. Tensile St.	68,000	45,000	83,000
Hardness BHN	120	95	150
Hardness R_b	75	60	88

The table shows the typical book mechanical properties of the three aluminum alloys vs. the properties after we had heat treated them to simulate the heat treatment that would be given the materials during the MoS_2 conversion process. (1) As expected the 2024-T4 Al was overaged slightly but the property values are still within the book average values. (2) The values obtained for the 6061-T6 Al are not those typical of the

(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	OGO (MoS_2)	673S-70-01	1200-42

CONCLUSIONS:

T6 condition but are typical of the T4 condition. This alloy in the sheet form is sold from the Mill in the T4 condition as it is then age hardened (T6 condition) by the buyer after fabrication. As the data showed, the heat treatment did partially age harden the alloy but not completely. (3) The 7075-T6 alloy shows a slight increase in its properties which indicates that some additional age hardening was caused by the treatment.

The microstructures shown in the photomicrographs indicate the changes in the mechanical properties values by the change in amounts of precipitates and small changes in grain size.

The following conclusions can be drawn:

(1) The heat treatment of 315° ± 15°F for 6 hours will not significantly affect the mechanical properties of 2024-T4 and 7075-T6 aluminum alloys. This treatment is similar to that used by Electrofilm Co. in putting their MoS_2 coating onto a substrate and is similar to the treatment given during the in situ deposition of MoS_2 as done at GSFC-MSB.

(2) The data obtained on the 6061 Al alloy was not applicable as the material was not in the T6 condition. But as the age hardening temperature for this alloy is 315 - 355°F, it is felt that no significant changes to its mechanical properties will be made by the 315°F treatment.

C. E. Vest 5-17-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
R. D. Mattingly	6	W-208	OGO	673S70-01	810-1

DATE IN	DATE COMPLETED	PERFORMED BY
8-20-63	10-8-63	W. G. Grenier and J. L. Wall

NAME OF TEST

Metallurgical Examination of Al Sample Race Discs

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

1-6061 Al, sample race disc, which had been coated with Alpha Molykote Spraykote prior to ball race test.

EQUIPMENT INVOLVED:

Model L Macro Camera, misc. hand tools, ultrasonic cleaner, standard Rockwell Hardness Tester, abrasive cut off wheel, glass filled epoxy mounting medium, wet belt surfacer, Handimet hand polisher, slow speed polishing wheels equipped with Automet attachments, hand polishing wheels, Fisher Vibratory polisher, HCl & HF etchants, B&L Research Metallograph.

RESULTS:

1. Hardness data given in Table-1, sheet 4, indicates 6061-T6 condition for substrate.
2. Photomacrographs are given in Figs. 2 & 3, sheet 5.
3. Examination of the microstructure in the wear track region showed no indication of cold work. Structure was normal.

W. G. Grenier 10-15-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1

PROCEDURE: General:

One experimental aluminum ball race was submitted by the Originator for Metallurgical examination. The ball race consisted of an 6061-T6 aluminum disc which had been cleaned in an NaOH solution and coated with Alpha Molykote Spraykote as a lubricant. It was desired that photomacrographs be prepared of the wear track to point up surface disturbances caused by the bearing balls. It was also desired to determine the presence of cold work in the wear track region and the hardness of the substrate aluminum.

Photomacrographs were prepared at 15 and 30 diameters, using the Bausch & Lomb Model L Macro Camera with a Polaroid back. Subsequently, the ring was cleaned in Trickloroethane ultrasonically. This cleaning removed all gross traces of the Spraykote. At this point it was observed that though a burnished ring appeared visible to the eye in location of the wear track; no depression could be felt or measured. The disc was cut into small sections by means of an abrasive cut off wheel. Several sections were mounted in glass filled epoxy, such that the exposed faces were representative of planes normal to the plane of the wear track surface. Therefore each mounted section contained a cross section of the wear track region.

Standard Rockwell E hardness tests were performed on unmounted sections of the clean aluminum disc. The mounted specimens were polished, following standard Metallurgical laboratory procedures. Final polish was accomplished, using the Fisher Vibratory Polisher with Gamal Alumina on Gamal cloth. Each specimen was etched in an HCl-HF solution to reveal the microstructure. The microstructure was examined

W. G. Grenier 10-15-63
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1

PROCEDURE: General:

with the B&L Research Metallograph under various magnifications, and no evidence of surface deformation or cold work was observed.

W. G. Grenier 10-15-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1
DATA: Photographic and Hardness			

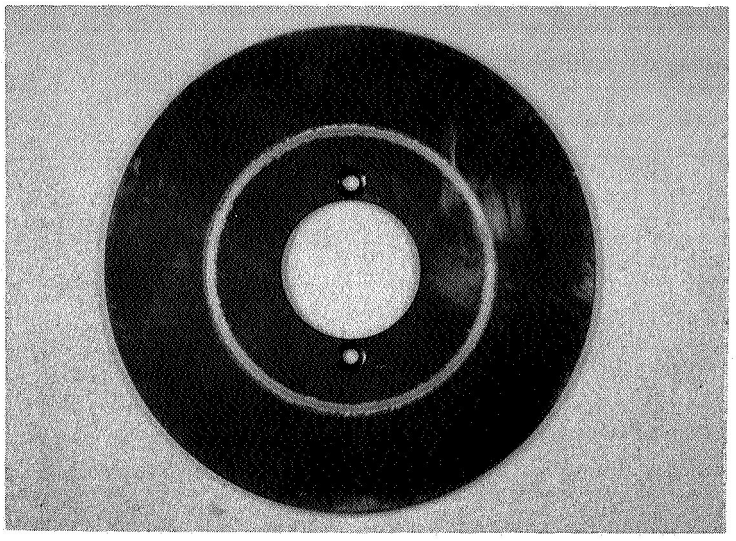

Figure 1-Photograph of experimental ball race as received, defining wear track.

Table 1
Substrate Hardness
Rockwell-'E'

Reading No.	Hardness No.
1	93
2	93
3	92-1/2
4	93

W. G. Grenier 10-15-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1

DATA: Photomacrographic

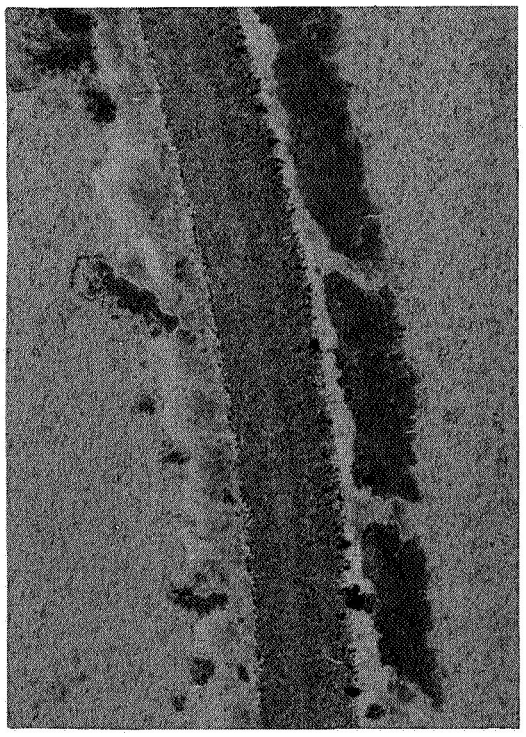

Figure 2 15 X

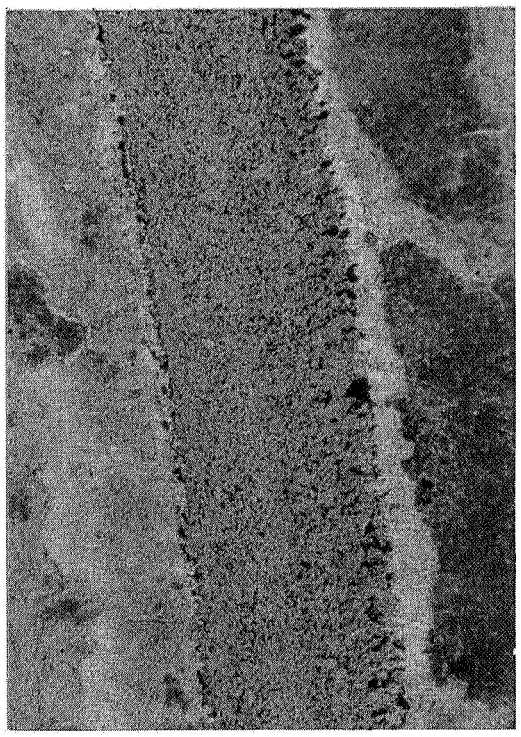

Figure 3 30 X

Macrographs showing wear track. These point up splaying of lubricant on the sides of the track, and some Molykote apparently burnished into intimate contact with substrate.

W. G. Grenier 10-15-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO S49 & OSO S50 S-17	673S70-01 673S69-01	810-1

CONCLUSIONS:

For a loading of 65,000 P.S.I. for a test period of over 72 hours on a heat cured spray coating of X106 MoS_2 the results are unusual and surprisingly good.

In the preliminary preparation of the test specimen no care was exercised to ready the piece for so severe a test. The results of the examination of the part tested indicate no metal penetration had occurred and residual MoS_2 was present on the metal surface. The implication here is that the spray, heat cured MoS_2, is a completely serviceable and useable lubricant for certain applications. "Dusting" appeared to be a slight problem and some flaking was evident. It is my opinion that this problem could be controlled or possibly prevented.

R. D. Mattingly 10-16-63
(Signature) (Date)

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
R. D. Mattingly	11	S-105	OGO	673S70-01	810-1

DATE IN	DATE COMPLETED	PERFORMED BY
9-27-63	12-2-63	W. G. Grenier & J. L. Wall

NAME OF TEST

Metallurgical Examination, Ball Bearing Test Effects

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Determine effects of ball bearing tests, and hardnesses of coatings, on four samples submitted by Originator. Samples as follows;

A-2: 6061 Al with Martin Hardcoat + X-106 lubricant

A-4: 6061 Al with Martin Hardcoat + M-88 lubricant

B-2: 6061 Al with Black Anodized Surface + X-106 lubricant

B-4: 6061 Al with Black Anodized Surface + M-88 lubricant.

EQUIPMENT INVOLVED:

Same as repotted under M.R. 63-17, dated 10-15-63, same Request No., plus the Kentron Microhardness Tester.

RESULTS:

1. For photographs of as received specimens see Figs. 2 & 3, Sheet #4.
2. For photomacrographs of wear tracks see Figs. 4-7 inc., Sheets 5 & 6.
3. For hardness data pertaining to coatings see Sheets 7-9 inc.
4. Metallographic examination of the substrate revealed no indications of deformation or cold work. This conclusion was verified by Mr. C. E. Vest, Metallurgical Engr.
5. The substrate hardness of R/E-94-95 indicates the material to be in the T6 condition.

W. G. Grenier 12-2-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1

PROCEDURE: Four (4) experimental ball races were submitted by the Originator for Metallurgical examination. All ball races consisted of 6061-T6 Al discs which had been coated differently. Figure-1, sheet 3, shows the make up of coatings and lubricants used for each specimen.

It was desired that photographs and photomacrographs be prepared of the wear tracks, to point up the typical surface disturbances caused by the bearing balls. It was also desired to determine the presence of deformation, or cold work, in the substrate microstructure in the region of the wear track and any variation in hardness, with respect to depth, of the coatings used.

In general, the procedures outlined in the report on S.R. 810-1, dated 10-15-63, were followed here. The exceptions to those procedures are as follows:

1. Photomacrographs pointing up the wear tracks were prepared at 15 diameters only.

2. Microhardness determinations were performed using a 50 gram load at various levels of the coatings. This was accomplished by taking a series of readings on the surface of a clean, unmounted portion of a disc, then polishing on 600 grit silicon carbide paper until a small amount of the coating was removed. At this point another set of microhardness readings were taken. This procedure was continued until, even with the light 50 gram load, the diamond indenter broke through the remaining film of coating. Depth levels into the coating were determined by measuring the thickness of the disc, before and after each polishing operation, with a pair of 0-1" micrometer calipers capable of being read to 0.0001".

W. G. Grenier 12-2-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1

DATA: Specimen Description

SPECIMEN IDENTIFICATION	COATING	LUBRICANT
A-2	Martin Hardcoat	X-106
A-4	Martin Hardcoat	M-88
B-2	Black Anodize	X-106
B-4	Black Anodize	M-88

Fig. 1-Make up of coatings and lubricants for each specimen tested.

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(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1
DATA: Photographic			

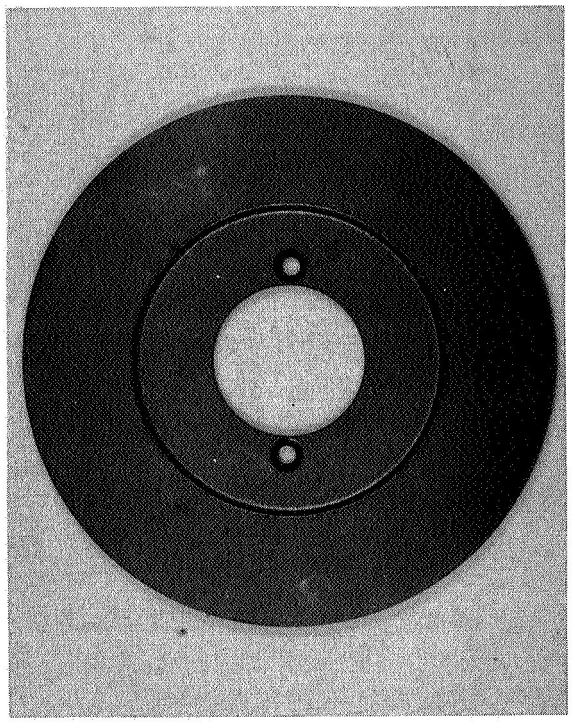

Fig. 2-Experimental Ball Race of 6061-T6 Al employing Martin Hard Coat and a lubricant.

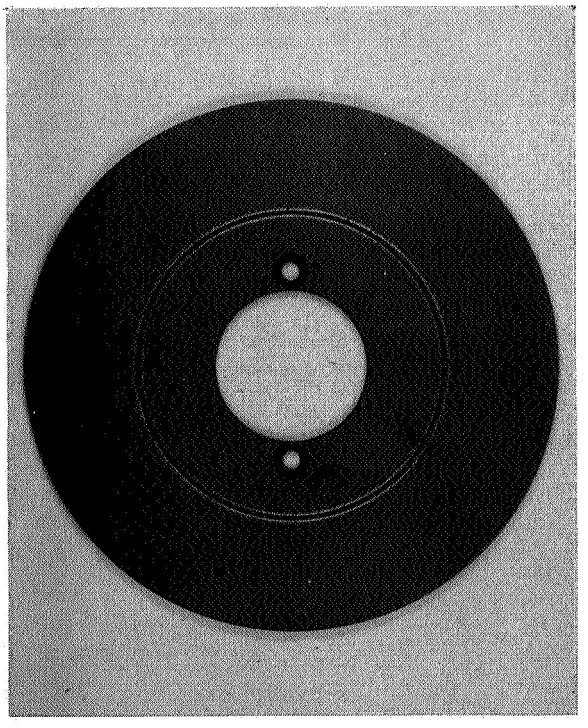

Fig. 3-Experimental Ball Race of 6061-T6 Al employing a Black Anodized coating and a lubricant.

Figures 2 and 3 are photographs of the 6061-T6 Aluminum experimental ball races in the as received condition and point up the wear tracks. Photographic exposures were identical for both specimens.

W. G. Grenier 12-2-63

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1
DATA: Photomacrographic			

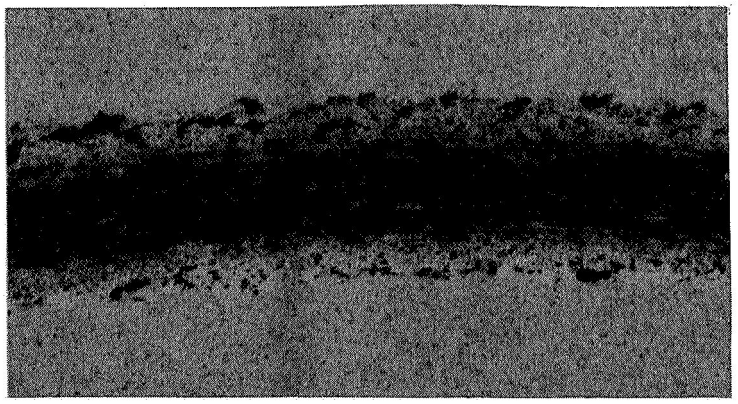

Fig. 4-Wear track on Martin Hardcoat treated 6061-T6 Al, with X-106 lubricant. Specimen A-2. 15 X.

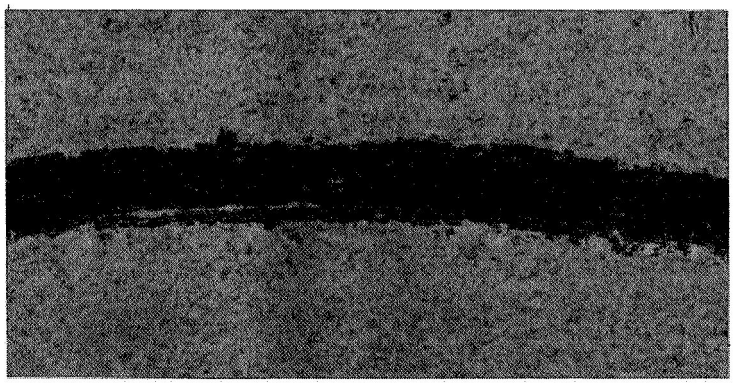

Fig. 5- Wear track on Martin Hardcoat treated 6061-T6 Al, with M-88 lubricant. Specimen A-4. 15 X.

W. G. Grenier 12-2-63
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1
DATA: Photomacrographic			

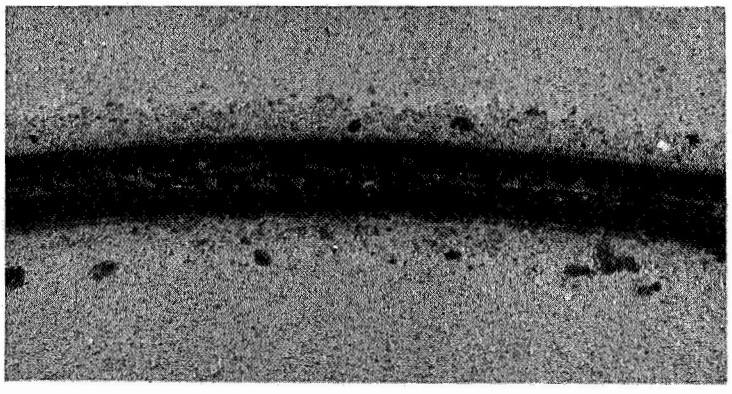

Fig. 6-Wear track on Black Anodized 6061-T6 Al, with X-106 lubricant. Specimen B-2. 15 X.

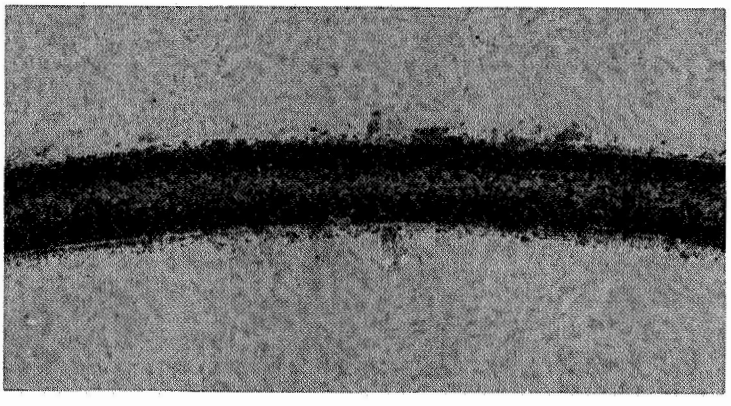

Fig. 7-Wear track on Black Anodized 6061-T6 Al, with M-88 lubricant. Specimen B-4. 15 X.

W. G. Grenier 12-2-63

(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1

DATA: Microhardness Tests employing a 50 gram load

Table 1

Specimen Ident.	Coating Type	Depth Into Coating Ins.$\times 10^{-3}$	Hardness		Specimen Ident.	Coating Type	Depth Into Coating Ins.$\times 10^{-3}$	Hardness	
			D.P.H.N.	R/C				D.P.H.N.	R/C
A-2	Martin	0	---	--	B-2	Black	0	---	--
	Hard	1.0	435	44		Anodize	1.0	447	45
	Coat	1.4	532	51			1.1	447	45
		1.5	541	52			1.2	424	43
		1.6	532	51			1.3	---	--
		1.7	532	51					
		1.8	---	--	B-4		0	---	--
							0.5	412	42
A-4		0	447	45			0.7	424	43
		0.5	501	49			1.0	---	--
		1.5	532	51					
		1.8	532	51					
		2.1	532	51					
		2.2	517	50					
		2.3	---	--					

Hardness values in Diamond Pyramid Hardness Numbers and converted standard Rockwell 'C' values for specific depths in the designated coatings. Where possible, the immediate surface hardness of the coating was determined, however, in general the coating surface was too rough for accurate readings.

The final depth tabulated, is that level at which the remainder of the coating was too thin to yield accurate hardness data.

W. G. Grenier 12-2-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1

DATA: Hardness versus Depth into Martin Hardcoat

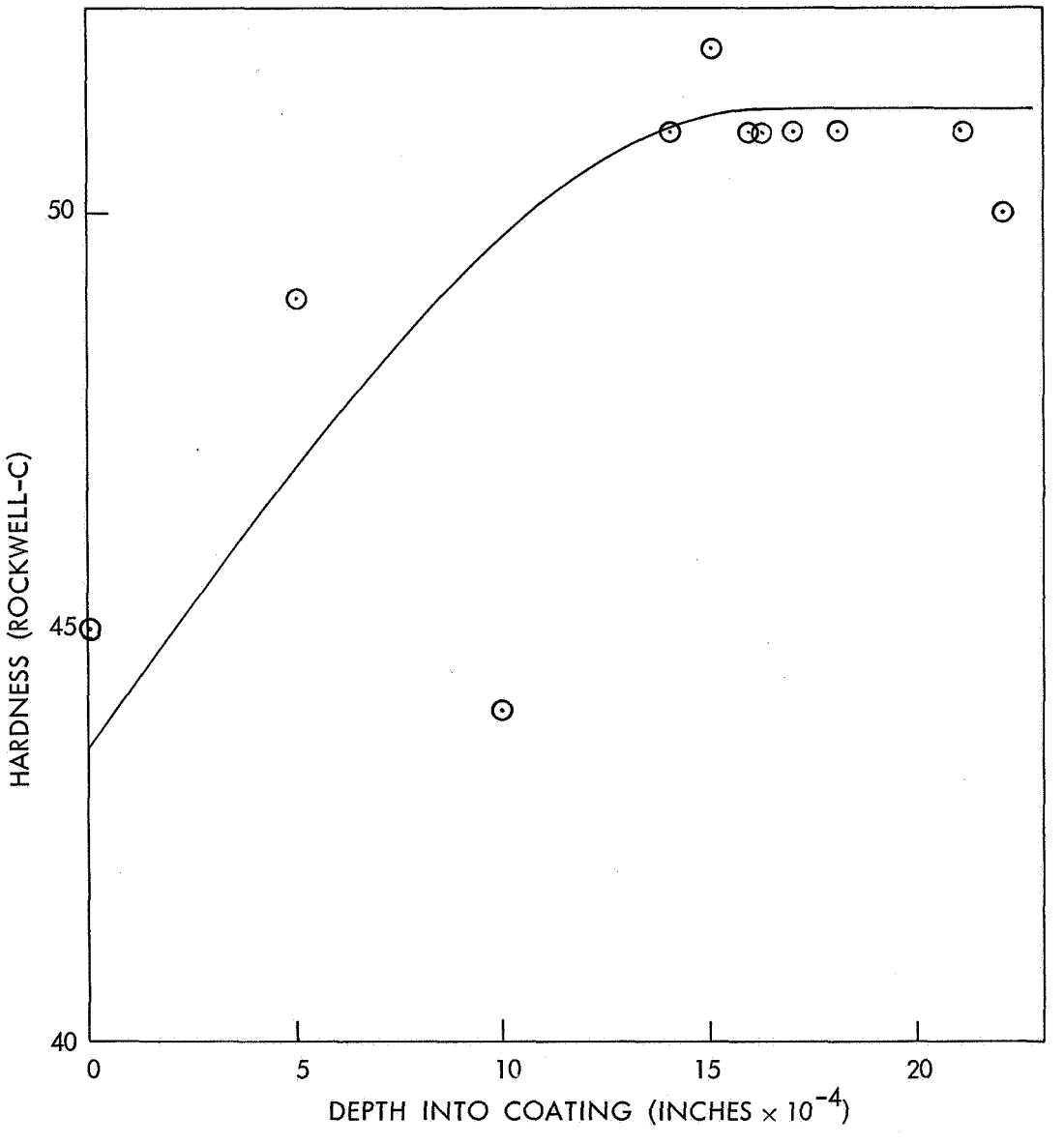

Figure 8-Effect of depth level on Hardness of Martin Hardcoat applied to 6061-T6 Al Experimental Ball Races.

W. G. Grenier 12-2-63
(Signature) (Date)

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1

DATA: Hardness versus Depth into Black Anodized Coating

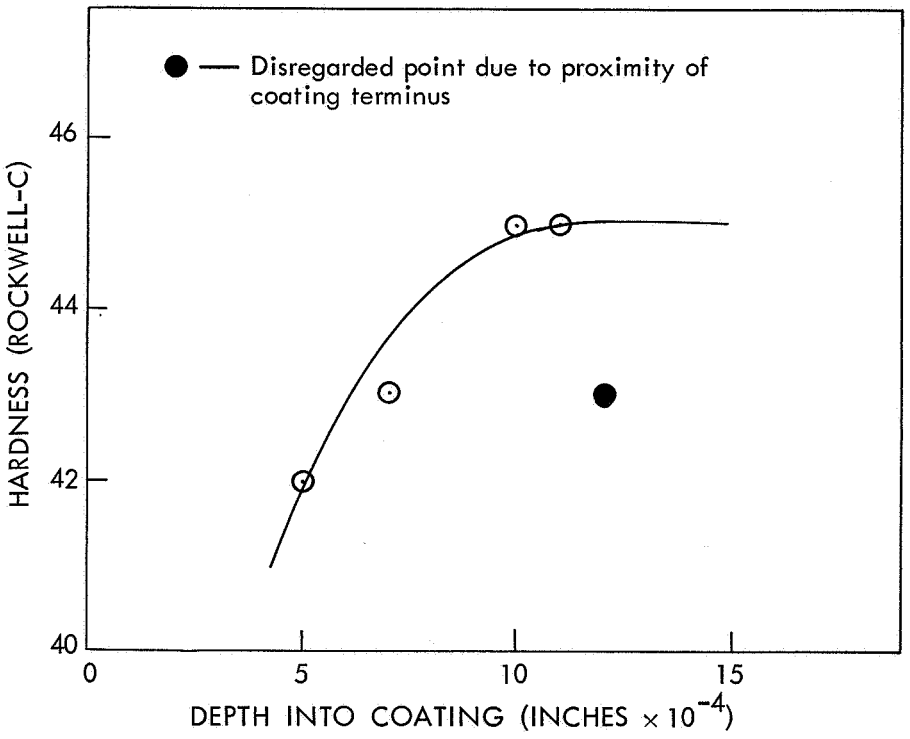

Figure 9-Indication of effect of depth level on the Hardness of the Black Anodize coatings applied to 6061-T6 Al Experimental Ball Races.

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(Signature) (Date)

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. D. Mattingly	OGO	673S70-01	810-1

CONCLUSIONS:

The service report Req. #810-1 confirms published information on hardness to be expected from the products used. In view of the relatively severe loading conditions and the "gross" approach to the problem it may be concluded that when specific applications arise the use of the Alpha Molykote Products should be investigated further for their potential usefulness.

R. D. Mattingly 12-9-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C. E. Vest	11	S-120	POGO Airglow	673S70-03	830-4

DATE IN	DATE COMPLETED	PERFORMED BY
11-8-63	12-9-63	W. G. Grenier

NAME OF TEST

Metallurgical Examination

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Failed base of Airglow Experiment

Unfinished blank base

Fracture mirror mounting bracket

EQUIPMENT INVOLVED:

B & L Model L Camera with Polaroid back and with Royal Ortho sheet film, abrasive cut off machine, wet belt surfacer, glass filled epoxy cold mount and bakelite ring forms, three wheel slow speed, polishing table equipped with Automet polishing heads, Fisher vibratory polisher, B & L Model DMETR Metallurgical Microscope, Unitron Metallograph with Xenon light source, Kentron Microhardness tester, Standard Rockwell hardness tester. Buehler Powermet Mounting Press, Handimet hand polisher, two wheel hand polishing table, Diamond paste and aluminum oxide abrasives, chemical reagents, B & L Research Metallograph, photographic dark room facilities, ASTM Standards Pt. 2, Metals Handbook Vol. 1, 8th edition, Dow Magnesium Design, Structures & Properties of Alloys by Brick & Phillips, 2nd edition.

RESULTS:

1. Black coloration on fracture surfaces was surface condition only.
2. Properties of specific alloys, see sheet 12.
3. Hardness tests, as received items, Table-1, sheet 13.
4. Hardness tests, lab heat treated items, Table-2, sheet 14.
5. Photographs, as received items, Figures 1-5 incl. sheets 15 and 16.
6. Photomacrographs, as polished specimens, Figures 6 and 7, sheet 17.
7. Photomicrographs, as polished specimens, Figures 8-10 incl., sheets 18 and 19.
8. Photomicrographs, microstructure, Airglow Bases, Figures 11-14, sheets 20 and 22.
9. Photomicrographs, microstructure, Mirror Bracket, Figures 15-17, sheets 23 and 24.

W. G. Grenier 12-10-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO AIRGLOW	673S70-03	830-4

PROCEDURE: General

Three (3) items, purportedly of ZK60A wrought magnesium alloy and designed for use in the POGO Airglow experiment, were submitted by the Originator for Metallurgical Examination. Two items, a fractured Airglow base and a fractured mirror mounting bracket, had failed during vibration testing. They failed after 10^6 cycles and a black coloration was observed on the fracture surfaces. The third item was an unfinished Airglow blank base. Photographs of the items, as received, are shown in the data as Figures 1-5 inclusive.

It was desired to determine the following: (1) If the failed items were defective prior to the vibration tests, (2) Whether the black coloration on the fracture surfaces was an integral part of the basis metal structure, or a post failure surface deposit. (3) If there existed any variation between the failed base and the unfinished blank base.

W. G. Grenier 12-10-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

PROCEDURE: Specimen Selection and Orientation

While several specimens were observed, only five (5) were micrographically evaluated for this report. Those five (5) consist of the following:

Specimens numbered 1 & 2, showing cross sections of the failed Airglow base.

Specimen number 3, showing a cross section of the unfinished blank base.

Specimen number 4, showing a cross section of the vertical portion of the fractured mirror mounting bracket.

Specimen number 5, showing the flat section of the fractured mirror mounting bracket, in a plane nearly parallel to the fracture surface.

Due to microstructural and hardness value discrepencies, noted later, additional specimens were selected from the two bases for laboratory heat treatment and hardness testing. Also, the Dow Chemical Company Brochure, titled Dow Magnesium Design, was consulted to determine the properties of specific magnesium alloys. The properties of the pertinent alloys are recorded on sheet 14 of the data.

Each item was sectioned, using the abrasive cut-off machine with abundant coolant. The failed Airglow base was sectioned at a location well removed from the fracture zone, see figure - 1, sheet 15. Those specimens taken from both the failed and the blank Airglow bases, were mounted such that the surface to be polished contained a plane coincident with the longitudinal axis of symmetry of the given base. The result of this is a true cross sectional configuration of the base. Two specimens were prepared for the failed base and one for the unfinished blank base. The failed mirror mounting bracket was

W. G. Grenier 12-10-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

PROCEDURE: Specimen Selection and Orientation Cont'd.

received in two pieces and was prepared in two separate mounts, see figure 3, sheet 15. The sections were each mounted such that the fracture surfaces would be as near parallel as practicable to the polishing plane.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

PROCEDURE: Specimen Mounting

Since edge retention was desired, the mounting medium chosen was glass filled epoxy, poured over the individual specimens while within 1-1/4" bakelite ring forms. The medium consisted of; three (3) parts, by weight, Hysol 2038 epoxy mixed with two (2) parts, by weight, of 325 mesh ground glass. The glass and epoxy mix was combined with Hysol Hardener 3404 in the weight ratio of sixteen (16) parts mix to one (1) part hardener. This preparation was not fully hardened, after sitting at room temperature for thirty hours. Therefore the specimens were placed in the heat treatment furnace and held at 120°F for an additional twenty four hours. Following the hot cure, they appeared to be fully hardened. Additional similar specimens, from the two bases only, were prepared using a combination of fourteen (14) parts mix to one (1) part hardener. This combination was fully cured after twenty four hours at room temperature.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

PROCEDURE: Specimen Polishing

Prepatory to polishing, each specimen was rough ground on the wet belt surfacer, using a 120 grit silicon carbide belt. Polishing, for the as polished study of the specimens, was accomplished on the three wheel, slow speed, lapping table, equipped with Automet attachments for each wheel. Copious quantities of tap water were used on the papers. A light load setting (20 pounds) was used on the Automet with the maximum time of one minute running time for each step. Final polish was accomplished using Beuhler-Gamma Alumina No. 3 abrasive, dispersed in distilled water, with a Selvyt cloth on an aluminum wheel.

While this procedure rendered an adequate surface for the as polished metallography, macrophotography and microhardness determinations, it was inadequate for microstructural evaluations. Therefore the five specimens were repolished, starting with the papers on the Handimet hand polisher. Triple filtered liquid soap, was used with distilled water, as a carrier and lubricant on both, the 600 grit Alundum wheel and the final Gamma Alumina charged wheel. The cloth was used on the final wheel was Selvyt.

A light, but firm, pressure was applied to the specimens, with each polishing stage lasting only long enough to remove the previous stage scratches. This procedure produced a good metallurgical polish.

It was observed, very early in the polishing operations, that the black coloration on the fracture surfaces of specimens numbered 4 & 5 was eliminated with a minimum amount of abrading. This indicates that the coloration was probably in the nature of a post fracture deposit.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

PROCEDURE: Hardness Tests

Microhardness tests were performed on all specimens following the final automet polishing step. The Kentron Microhardness tester was employed, using a 500 gram load and the 20× objective lens. Three readings were taken on each item and the data recorded.

Hardness values for the various tempers of the magnesium alloys are given, in the literature, as either Brinell or Rockwell E numbers. Therefore the Dyamond Pyramid Numbers, obtained from the Microhardness readings, were converted to Brinell numbers. For this purpose, the conversion table number V of the ASTM Standards, Part-2, 1958 edition was used. Standard Rockwell E hardness tests were also performed on specimens of each item submitted. The Rockwell E Tests were performed on the material from both bases, both before and after the laboratory heat treatment. The hardness data is tabulated in tables 1 & 2, sheets 12 & 13.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

PROCEDURE: Metallography

Following the final Automet polishing step, photomicrographs of specimens numbered 1 & 3 were prepared, using the Model-L macro camera. They are shown in figures 6 & 7, sheet 16, of the data. They point up the sharp interior corner of the failed base, the generous fillet in the corner of the unfinished blank base, and the taper of the side on the blank base.

Photomicrographs, at magnifications of 400 diameters, were prepared of the corner zone of the failed base, and at 50 diameters of the corner zone of the blank base. The micrographs were prepared, using the Unitron Metallograph with Royal Ortho sheet film, and are shown as figures 8-10 inclusive, in the data sheets numbered 17 & 18. The microscopic cracks radiating from the sharp angle, or notch, in figures 8 & 9, were not observable to the naked eye. They were first observed in the B & L bench microscope, during a routine check on polishing efficiency.

Subsequent to the repolishing procedures, outlined earlier in this report, photomicrographs were prepared of the microstructures, in the same areas shown in the as polished condition. One photomicrograph, at a magnification of 250 diameters, was prepared as typical for the Airglow bases and is given as figure 11, sheet 19, in the data. Other photomicrographs, at 250 diameters, showing the transgranular characteristics of the aforementioned cracks, are presented in figures 12 & 13, sheet 20. The microstructure at the root of the fillet is presented at a magnification of 250 diameters in figure 14, sheet 21. Figures 15-17 inclusive, sheets 22 & 23, show the typical basis material microstructure

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	637S70-03	830-4

PROCEDURE: Metallography (Cont'd)

for the mirror mounting bracket, at magnifications of 100 and 250 diameters.

All microstructure, photomicrographs, figures 11-17 inclusive, were prepared on the B & L Research Metallograph. Metallographic plates were used with Kodak DK-60 as the developer and 6 minutes development time. Standard darkroom procedures were followed in reproduction of contact prints. In every case the etchant used consisted of: 5% Picral – 100cc, Glacial Acetic Acid – 5cc, and Distilled water – 10cc. Etching time is from 5 to 20 seconds by immersion.

Structures and Properties of Alloys – 2nd. Edition, by Brick and Phillips, was consulted as to etching techniques and typical microstructure of the ZK60A magnesium alloy. The microstructure of the two sumbitted Airglow bases, was not typical of the purported alloy. Therefore the Originator was consulted, who on checking back with the manufacturer, learned that the bases were in fact fabricated from an AZ31B magnesium alloy and were purportedly in the H-24 condition. The revealed microstructure, figure-11, is typical of an AZ31B alloy.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

PROCEDURE: Laboratory Heat Treatment

Due to the apparent O temper of the AZ31B alloy used in the bases, as revealed by the data, additional tests were made. Several specimens of each of the bases were sectioned and given a full anneal treatment, in accordance with the A.S.M. Metals Handbook, Volume-1, Eighth Edition. This was accomplished in the laboratory heat treatment furnace. The specimens were; heated to 650°F, held for 1 hour, furnace cooled to 200°F, and removed for hardness tests. No significant change in hardness was shown by the data as compiled in Table-2, sheet 13.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

DATA: Properties of Specific Magnesium Alloys:

1. Chemical Compositions

   Dowmetal ZK60A: 5.5% Zn, 0.5% Zr, Bal. Mg.
   Dowmetal AZ31B: 3.0% AZ, 1.0% Zn, 0.2% Mn, Bal. Mg.

2. Mechanical Properties at Room Temperature

   A. Bars, Rods and Shapes

Alloy	Temper	B.H.N.	R/E
ZK60A	F	75	84
ZK60A	T-5	82	88
AZ31B	F	49	57

   B. Tubing

ZK60A	F	75	84
ZK60A	T-5	82	88
AZ31B	F	46	51

   C. Forgings

ZK60A	T-5	-	-
AZ31B	F	55	66

   D. Sheet and Plate

AZ31B	0	56	67
AZ31B	H-24	73	83

Notes: Temper - F = as extruded
Temper - T-5 = artificially aged
Temper - 0 = annealed
Temper H-24 = strain hardened then partially annealed.

Data from Dow Metal Co. Brochure – Magnesium Design, 1957 edition.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4
DATA: Hardness Tests, As Received Samples			

Table 1

Specimen Identification	Microhardness Test Data Kentron: 500 Gram Load, 20X Objective				Standard Rockwell 'E' Hardness
	Reading No.	Average Diagonal F.U.	D.P.H.N.	Converted Brinell No.	
Failed Base	1	283	58	53	65-1/2
	2	274	61	56	65
	3	275	61	56	65-1/2
Blank Base	1	274	61	56	64
	2	273	62	57	64
	3	279	69	54	63-1/2
Mirror Mounting Bracket	1	230	87	78	78
	2	229	88	79	76
	3	236	83	75	75

Rockwell E values listed above, were taken independantly of the other hardness tdsts using a 1/8 inch diameter ball with 100 KG load.

Conversion from D.P.H.N. to Brinell numbers were obtained from ASTM standards for Non-Ferrous metals, 1958 Edition, Table V.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4
DATA:	Hardness Tests, Laboratory Heat Treated Specimens Dow Metal AZ31B Alloy		

Table 2

Specimen Identification	Microhardness Test Data Kentron: 500 Gram Load, 20X Objective				Standard Rockwell 'E' Hardness
	Reading No.	Average Diagonal F.U.	D.P.H.N.	Converted Brinell No.	
Failed Base	1	258	69	62	64-1/2
	2	255	71	63	63
	3	261	68	62	63-1/2
Blank Base	1	256	70	63	63-1/2
	2	265	66	61	64
	3	256	70	63	64

Heat treatment to produce full annealed condition of the AZ31B alloy in accordance with A.S.M. Metals Handbook, Volume 1, 8th Edition.

See notes at bottom of Table 1, preceeding sheet.

There is no marked change in hardness due to heat treatment.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4
DATA: Photographic, Items As Received			

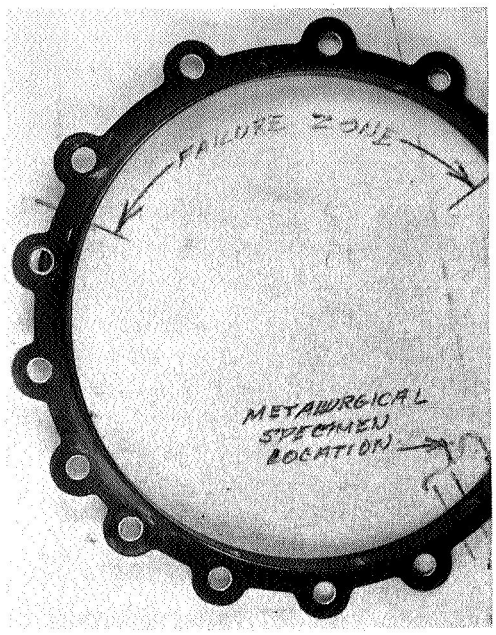

Figure 1– Failed Airglow Base

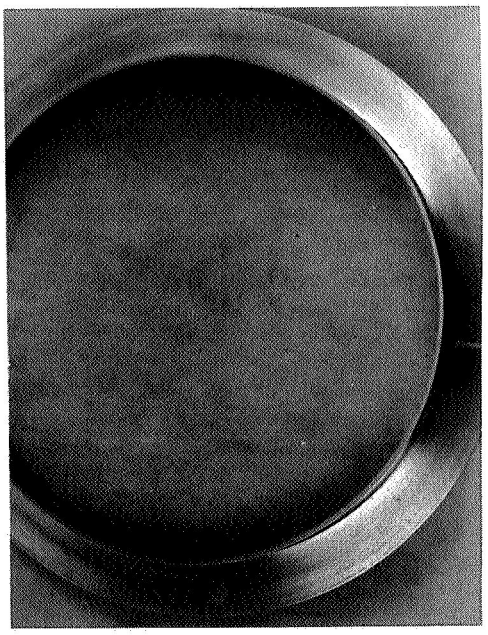

Figure 2–Unfinished Airglow Base Blank

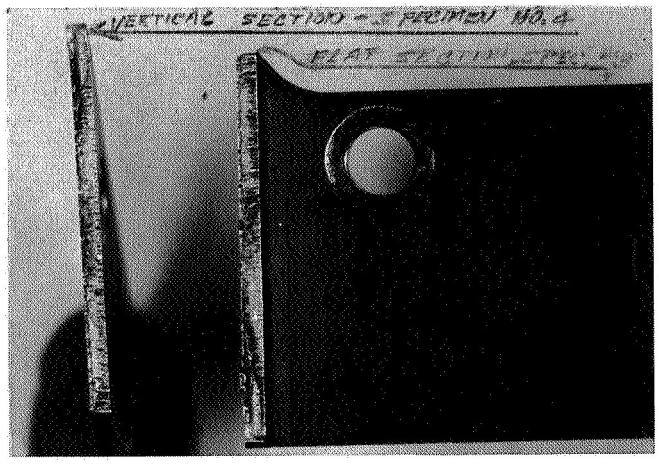

Figure 3–Failed Mirror Mounting Bracket
(Note black residue on fracture surface)

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4
DATA: Fracture Photographs, Failed Airglow Base			

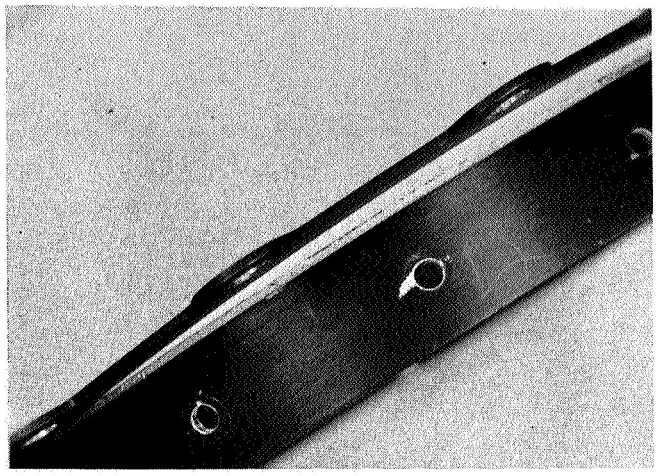

Figure 4 1-1/2 X

Points up fracture face and location with slight black deposit on edge of fracture.

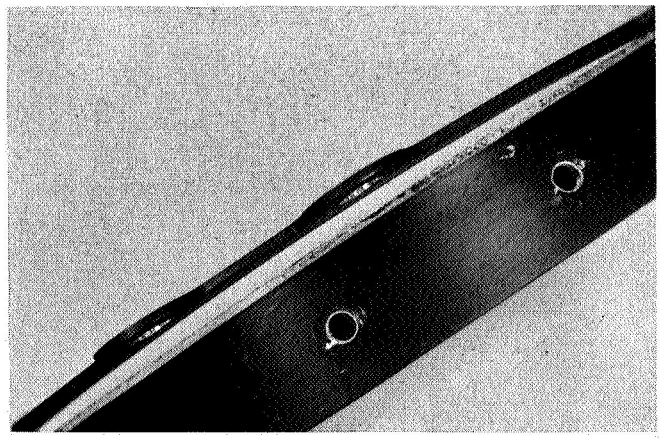

Figure 5 1-1/2 X

Points up black residue on the fracture surface.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

DATA: Photomacrographs

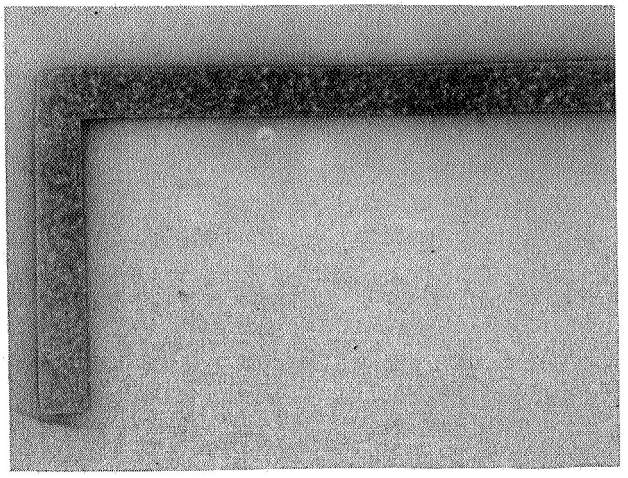

Figure 6 7-1/2 X

Photomacrograph of polished cross section of failed Airglow base. Note sharpness of interior corner.

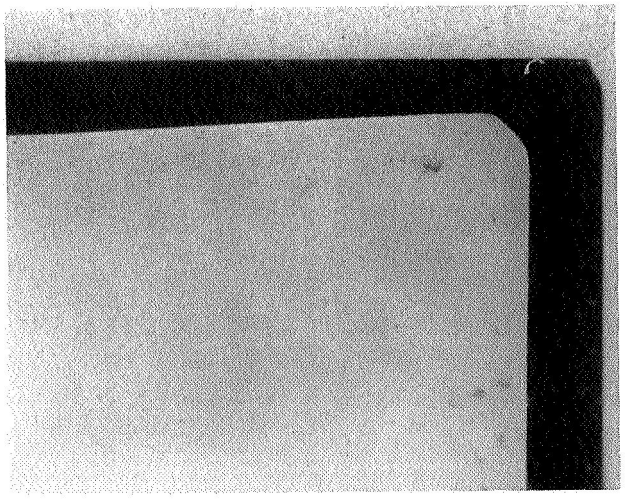

Figure 7 11 X

Photomacrograph of polished cross section of unfinished Airglow base-blank. Note generous fillet in interior corner, and taper of side member.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

DATA: Photomicrographs, Cross Section Failed Airglow Base as Polished, Specimens

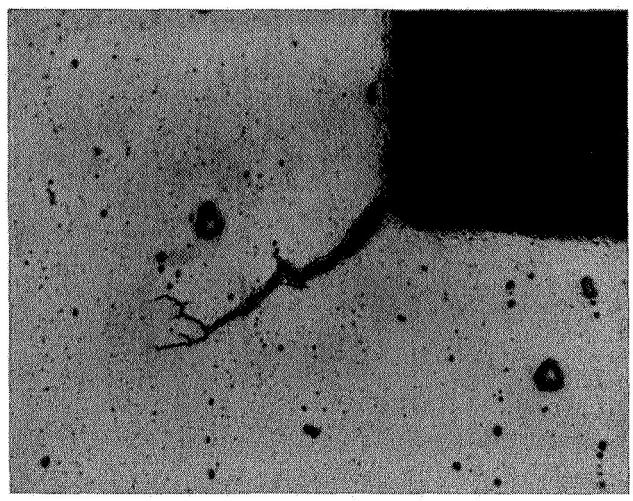

Figure 8–Specimen #1 400 X

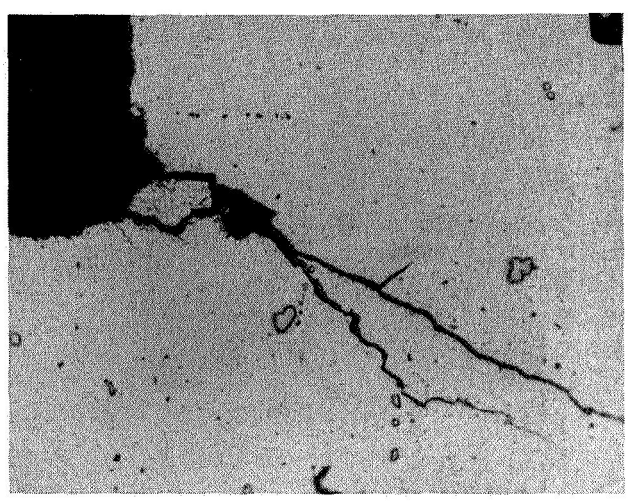

Figure 9–Specimen #2 400 X

Figures 8 & 9 show cracks radiating from sharp corner, in area indicated in Figure 1.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4
DATA:	Photomicrographs, Cross Section Unfinished Airglow Base Blank. As Polished Specimen.		

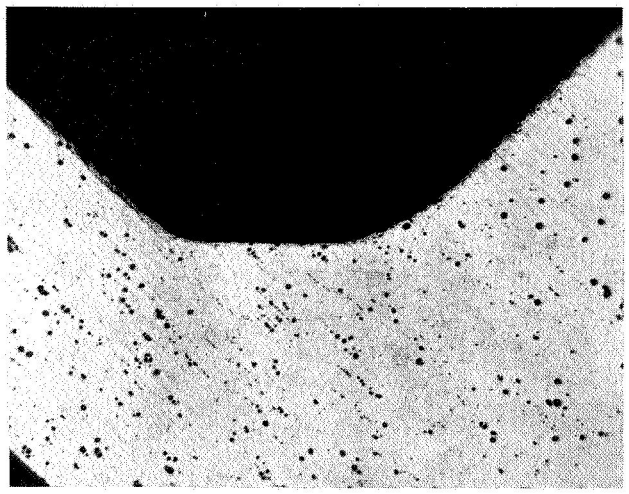

Figure 10--Specimen #3 50X

Shows shape of fillet in unfinished Airglow Base Blank. See Figure 2.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

DATA: Photomicrograph, Airglow Base

Figure 11 250 X
Etch: Picral-Acetic

The Microstructure in Figure 11 is typical of the basis material for both the failed Airglow base and the unfinished Airglow base blank.

This microstructure is typical for the Dow Metal AZ31B alloy.

Hardness: Brinell No. 53-57, converted from D.P.H.N. 58-62.

The large grains coupled with the hardness values, indicate the 0 temper.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

DATA: Photomicrographs, Failed Airglow Base

Figure 12–Specimen #1 250 X

Figure 13–Specimen #2 250 X

Etch: Picral-Acetic
Mtl.: Dowmetal AZ31B alloy

The photomicrographs in Figures 12 & 13 show the typical cross section microstructure of the failed Airglow base, in that area indicated in Figure 1. They point up the transgranular character of the microscopic cracks originating at the machined notch. From observation of other specimens, it was determined that the cracks shown are typical of the base throughout that area.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Ariglow	673S70-03	830-4
DATA: Photomicrograph, Airglow Base Blank			

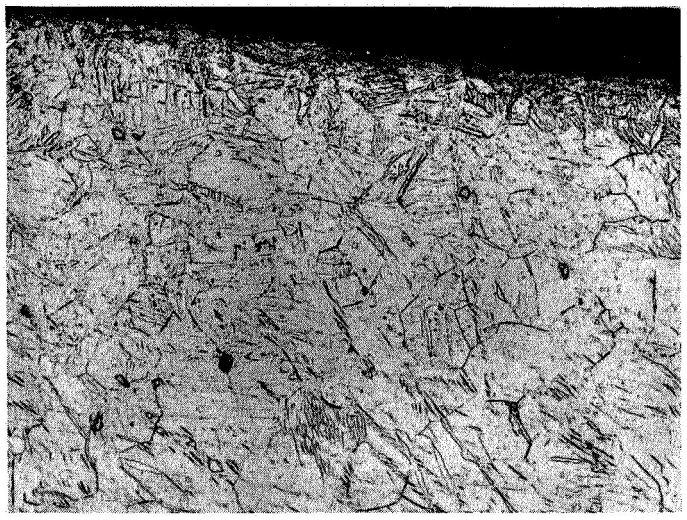

Figure 14–Specimen #3 250 X

Etch: Picral-Acetic
Mtl.: Dowmetal AZ31B alloy

Typical of microstructure at base of fillet, in cross section of Airglow unfinished base blank.

There are no apparent abnormalities.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

DATA: Photomicrograph Failed Mirror Mounting Bracket. Vertical Section

Figure 15–Specimen #4 250 X

Mtl.: Dowmetal ZK60A alloy
Etch: Picral-Acetic
Hardness: Brinell No. 77, converted from D.P.H.N. Standard Rockwell 'E' 74-78

Figure 15 shows typical cross section microstructure of vertical section indicated in Figure 3. Cross section is in plane parallel to fracture face.

On polishing, the black deposit, seen in Figure 3, was eliminated. This indicated that the black substance was in fact a deposit and not impurities in the basis metal.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	POGO Airglow	673S70-03	830-4

DATA: Photomicrographs, Failed Mirror Mounting Bracket
Flat Section

Figure 16 100 X

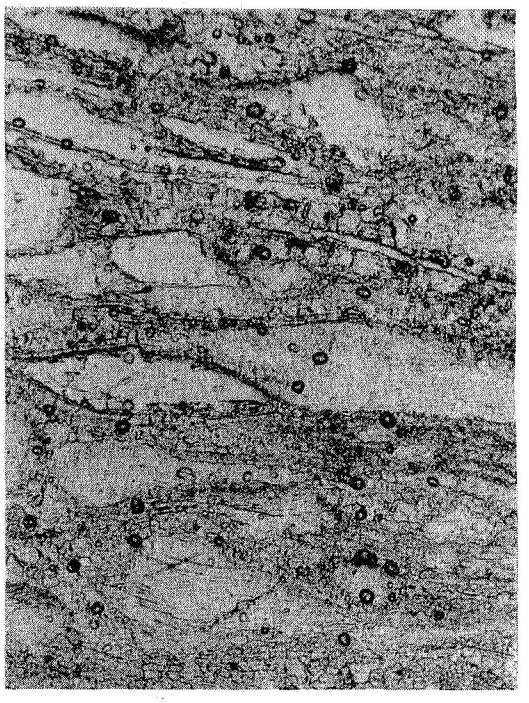
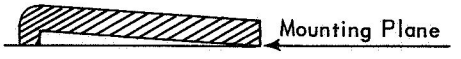


Figure 17 250 X

Specimen #5



Mtl.: Dowmetal ZK60A alloy
Etch: Picral-Acetic
Hardness: Rockwell 'E' 74-78

Figures 16 & 17 show the microstructure typical of the flat section indicated in Figure 3. The observed plane is indicated in the sketch above.

The large grains shown in Figures 16 & 17, coupled with the low hardness, indicate that the material is in the annealed condition.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C. E. Vest and T. W. Flately	Beltsville	125 & 114	Phase II of Bearing Prog.	673Y03-13	1200-6

DATE IN	DATE COMPLETED	PERFORMED BY
4-3-63	4-16-63	W. G. Grenier

NAME OF TEST

Microhardness Tests

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

The Diamond Pyramid Hardness Number and its corresponding standard Rockwell 'C' value was determined for each of ten (10) retainers. The retainers were from bearings which had been test run in Phase II of the bearing program.

EQUIPMENT INVOLVED:

Buehler Mounting Press, Lucite powder, Handimet hand grinder, 6μ diamond paste, Automet and slow lapping wheel with silk cloth at low setting, Kentron Microhardness tester.

RESULTS:

See data on Sheets 3 & 4.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest and T. W. Flately	Bearings Program	673Y03-13	1200-6

PROCEDURE:

1. Each retainer was mounted in lucite

2. Each retainer was polished through the papers on the Handimet.

3. Polish each retainer on slow lapping wheel, at low setting, using 6μ diamond paste on silk, with Automet set at 40 pounds for 5 minutes.

4. Using Kentron Microhardness tester with 500 gram load and 50X objective, take a minimum of four (4) hardness readings on each retainer, and convert to D.P.H.N.

5. Convert D.P.H.N. to Rockwell 'C' values, using ASTM Standards, 1958 edition Part 3.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest and T. W. Flatley	Bearings Program	673Y03-13	1200-6

DATA: Kentron Microhardness Tester. Load = 500 grams, Objective = 50 X

Specimen No.	Test Run No.	Read. No.	Avg. Diag. F.U.	D.P.H.N.	Convert to R/C	Specimen No.	Test Run No.	Read. No.	Avg. Diag. F.U.	D.P.H.N.	Convert to R/C
1	5	1	325	218	17	5	XXV	7	268	321	33
"	"	2	326	216	16	"	"	8	258	346	35
"	"	3	319	226	18	"	"	9	249	370	38
"	"	4	323	220	17	"	"	10	248	375	38
"	"	5	325	218	17	"	"	11	269	318	32
2	10	1	325	218	17	6	XXVI	1	271	314	32
"	"	2	320	224	18	"	"	2	267	323	33
"	"	3	323	220	17	"	"	3	265	328	33
"	"	4	323	220	17	"	"	4	258	346	35
3	6	1	244	385	39	7	46	1	277	300	30
"	"	2	243	390	40	"	"	2	275	305	30
"	"	3	240	401	41	"	"	3	275	305	30
"	"	4	241	395	40	"	"	4	273	309	31
4	11	1	250	368	37	8	49	1	280	294	29
"	"	2	245	384	39	"	"	2	281	292	29
"	"	3	241	395	40	"	"	3	280	294	29
"	"	4	243	390	40	"	"	4	280	294	29
"	"	5	243	390	40						
						9	47	1	176	740	62
5	XXV	1	268	321	33	"	"	2	177	735	62
"	"	2	245	384	39	"	"	3	176	740	62
"	"	3	256	351	36	"	"	4	177	735	62
"	"	4	273	309	31						
"	"	5	248	375	38						
"	"	6	261	338	34						

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest and T. W. Flatley	Bearing Program	673Y03-13	1200-6

DATA: Kentron Microhardness Tester. Load = 500 grams, Objective = 50 X.

Specimen No.	Test Run No.	Reading No.	Average Diagonal F.U.	D.P.H.N.	Convert to R/C
10	58	1	251	365	37
"	"	2	248	375	38
"	"	3	258	346	35
"	"	4	259	343	35
"	"	5	255	354	36

Specimen No.	Test Run No.	Material
1	5	Silicon Bronze
2	10	Silicon Bronze
3	6	Be Cu
4	11	Be Cu
5	XXV	S-Inconel
6	XXVI	S-Inconel
7	46	Circle-C Steel
8	49	Circle-C Steel
9	47	Hard Circle-C Steel
10	58	Hard Circle-C Steel

W. G. Grenier 4-17-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase II Bearings	67Y03-13	1200-6

CONCLUSIONS:

Job completed satisfactorily. Data will be published in Tech. Note.

C. E. Vest 4-12-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C. E. Vest	Beltsville	125	Phase III Bearings	673Y03-13	1200-36

DATE IN	DATE COMPLETED	PERFORMED BY
3-11-63	6-25-63	W. G. Grenier and J. L. Wall

NAME OF TEST

Investigation of Gold and Silver Plating Thickness and Integrity

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Articles Tested: Six virgin bearing assemblies, including Inner Race, Outer Race, and Bearing Balls. Four of the assemblies included retainers.

Service Rendered: Complete metallurgical examination of each component in each assembly.

EQUIPMENT INVOLVED:

Transoptic mounting powder, Buehler metallurgical-specimen mounting press, various hand tools, cut off machine, 0"-1" micrometer calipers, belt surfacer, Unitron bench microscope with micrometric stage, Buehler handimet hand polisher, fast and slow speed metallurgical polishing wheels, Automet Automatic polishing attachment, adhesive backed polishing paper disks for use with Automet, 6μ diamond, 1/4μ diamond, Gamal polishing Alumina, Ultrasonic cleaner, various chemical reagents, B & L Bench microscope, Kentron Microhardness tester, Unitron Metallograph, Model 'L' Macro camera, Polaroid camera attachments.

RESULTS:

Lea Ronal plating appears to be slightly heavier with a more uniformly tight bonding than does the Donovan plating.

For Component dimensions – Sheet #7
For Filar eyepiece calibration – Sheet #8
For Au and Ag plate thickness – Sheet #9
For Microhardness data – Sheet #10
Inner Race, Metallography – Sheets 11-15 inc.
Outer Race, Metallography – Sheets 16-21 inc.
Retainer, Metallography – Sheets 22-26 inc.
Bearing Ball, Metallography – Sheets 27-34 inc.

W. G. Grenier 6-29-63
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

PROCEDURE: Protective Plating, Rough Grinding & Polishing

Six unused, complete, bearing assemblies were submitted by the originator for plating thickness and integrity determinations. Each component of each assembly was plated with either gold or silver. Three assemblies were plated and assembled by Donovan and three by Lea Ronal, and were so designated. It was desired to determine any microstructural or plate thickness variations in the two platers results. It was noted that for each of the platers, one of the assemblies was of the type which did not utilize a separate retainer for the bearing balls.

The assemblies were received in the virgin, assembled condition, sealed in individual plastic envelopes. Each assembly was disassembled, the individual components carefully measured with micrometer calipers and their respective major diameters recorded. The disassembled components were submitted to Fabrication Division to have a nickel plating applied over the precious metal plating in each case. This was done as an aid in preservation of the relatively soft precious metal edge during the polishing processes. Upon receipt of the assembly components from Fabrication Division, each component was again carefully measured with micrometer calipers and the major diameters recorded.

Using standard Metallurgical Laboratory procedures, each component of each assembly was mounted in lucite such that its principal longitudinal axis was parallel to the plane of the mount surface. This statement does not apply in the cases involving bearing balls. Each specimen was then ground to within a few thousandths of an inch of its major diameter using the belt surfacer with a 120 grit silicon carbide belt. Each specimen was polished through the papers by hand with frequent checks being made to ensure that the top and

W. G. Grenier 6-26-63
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

PROCEDURE: Protective Plating, Rough Grinding & Polishing Contd.

bottom surfaces of the mount remained parallel. Frequent checks were also made (employing the Unitron bench microscope equipped with a micrometer stage and Filar micrometer eyepiece), of the breadth of each component as the midpoint was approached. Polishing was conducted in such a manner that when final polishing was completed, each specimen was within a few parts of one thousandth of an inch of its true midpoint. The final polish was achieved on the slow wheel at low speed using; the Automet polishing attachment, Gamal alumina abrasive, and a silk cloth. This produced flat specimens with little rounding of edges or reliefs due to varying hardness of constituents, but with many severe scratches. The scratches, while causing the specimens to be unsuitable for Metallographic purposes, in no way hindered their use in plating thickness determinations or in substrate hardness determinations.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

PROCEDURE: Plate Thickness and Hardness Measurements

The primary plate thickness of the precious metal plate was determined employing the B&L Metallurgical Microscope with its companion, Filar micrometer eyepiece. The Filar micrometer eyepiece was calibrated with each of the microscope objectives using a B&L 0.1 and 0.01 mm stage micrometer.

Hardness data was obtained on the substrate material, using the Kentron Microhardness tester with a 500 gram load and 50X objective. The D.P.H.N. so obtained was subsequently converted to standard Rockwell 'C' values.

Following the hardness determinations, each specimen was repolished to eliminate the aforementioned scratches. This was accomplished using the slow speed wheel at low setting with an Automet polishing attachment. Repolishing procedure is as follows:

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

PROCEDURE: Final Polishing and Etching Techniques

(1) 240 grit SiC paper at 20#-30# for 2 minutes

(2) 600 grit SiC paper at 30# for 2 minutes

(3) 6μ diamond on silk at 20#-30# for 2-1/2 minutes

(4) Gamal on microcloth at 30#-1 minute, 20#-1 minute.

This effected a good metallurgical polish with a minimum of scratches, however it also produced a slight rounding of component edges and relief of microconstituents.

Etching Procedures:

1. For 440C stainless steel substrate, with either Au or Ag primary plating, a modified Vilellas' etch was used. This consisted of 5 ml HCl + 2 ml Picric acid + 100 ml alcohol. Etch by immersion, up to 5 seconds, polish lightly by hand using Gamal on microcloth. Etch second time for from 10 to 15 seconds, judging final etch by appearance to the eye. This produces a clean surface but permits some rounding of edges and dragout of softer constituents.

2. For circle 'C' steel, which is a high W, Mo, Va, Cr, Co, alloy steel, a 4% HNO_3 in alcohol solution was employed with repolishing and etching procedures as in (1) above.

3. A second step etchant was employed to more clearly differentiate the Au and Ag plates from the protective nickel plate. The etchant used consisted of 1 part Glacial acetic acid and 1 part concentrated nitric acid. It was used to reveal the microstructure of the nickel plate. Etch by immersion for from 5-7 seconds. Since the acetic acid dissolves

W. G. Grenier 6-26-63

(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

PROCEDURE: Etching Techniques – Metallography

lucite, a thin film was left as a deposit on the specimen. This was removed by wiping very lightly on the last wheel.

Photomacrographs were prepared after the first etching procedure employing the B&L Model L Camera. The photomacrographs show the cross section of the mounted specimen as it was used for the metallographic examination. Photomacrographs are presented at 10 diameters, 15 diameters, and 20 diameters, depending on the specimens original size.

Photomicrographs were prepared at various magnifications using the Unitron Metallograph. Substrate microstructure and plating integrity is pointed up. The regions shown are usually those in the actual bearing area, however when an anomaly occurs, it too is shown. In general, the second step etch while aiding in plate delineation, frequently raised questions with respect to halation effects due to preferential attack. This etch was not used in the cases of the retainers due to the effect it would have on the substrate. In the instances where races were Ag plated the second step etch showed definite preferential attack on the silver.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Component Dimensions
Before & After Nickel Protective Plate Applied by Fabrication Division

Instrument = 0"-1" Micrometer Calipers

Assembly Identification	Nomenclature	Original Plater	Plate as Received	Diameter: Inches x 10^3	
				As Received	Post Nickel Plating
123C-D-7	Inner Race	Donovan	Au	Lost in Fabrication	
"	Outer Race	"	Au	374.8	402-405
"	Retainer	"	Ag	240.4	247.2
"	Balls	"	Au	62.2	68.2
124C-D-7	Inner Race	"	Au	179.0	184.9
"	Outer Race	"	Au	374.7	381.0
"	Balls	"	Au	62.2	65.5
142C-D-7	Inner Race	"	Ag	179.1	185.0
"	Outer Race	"	Ag	374.8	384.0
"	Retainer	"	Ag	240.5	244.1
"	Balls	"	Au	62.2	63.3
123C-LR-7	Inner Race	Lea Ronal	Au	179.1	184.7
"	Outer Race	"	Au	374.9	379.2
"	Retainer	"	Ag	240.7	245.1
"	Balls	"	Au	62.3	67.0
124C-LR-7	Inner Race	"	Au	179.1	184.4
"	Outer Race	"	Au	374.9	379.7
"	Balls	"	Au	62.3	66.8
142C-LR-7	Inner Race	"	Ag	179.2	187.4
"	Outer Race	"	Ag	375.2	380.7
"	Retainer	"	Ag	240.5	249.3
"	Balls	"	Au	62.3	68.6

W. G. Grenier 6-26-63
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36
DATA: Filar Eyepiece Calibration			

1. Calibrate Filar micrometer eyepiece for use on B & L Metallurgical Microscope. Calibrate with respect to each objective lens, using B & L 0.1 to 0.01 mm stage micrometer, and convert filar units to inches.

1mm = 0.03937 inches

8X objective lens: 0.5mm on stage micrometer = 436.5 filar units
1 filar unit = 0.0011455mm = 0.000045098 inches

10X objective lens: 0.5mm on stage micrometer = 545 filar units
1 filar unit = 0.0009174mm = 0.00003612 inches

20X objective lens: 0.4mm on stage micrometer = 900 filar units
1 filar unit = 0.0004444mm = 0.000017498 inches

40X objective lens: 0.2mm on stage micrometer = 900 filar units
1 filar unit = 0.0002222mm = 0.00000875 inches

Convert Filar Units to Inches	
Objective	Inches/Filar Unit Inches $\times 10^6$
8X	45.1
10X	36.1
20X	17.5
40X	8.65

This table is valid only when the B & L Filar micrometer eyepiece is used in conjunction with the B & L Metallurgical microscope bearing the N.A.S.A. identification number 34709.

NOTE: The thickness of one Filar hair is approximately two (2) filar units.

W. G. Grenier 6-27-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Plating Thickness Table. Instrument = B & L Metallurgical Microscope, 40X objective, with B & L Filar Micrometer Eyepiece

Assembly Identification	Nomenclature	Plate Material	Plate Thickness		Remarks
			Filar Units	Ins. $\times 10^6$	
123C-D-7	Inner Race	Gold	Lost in Fabrication Div.		
123C-D-7	Outer Race	Gold	3	26.3	
123C-D-7	Retainer	Silver	5	43.8	
123C-D-7	Balls	Gold	2-1/2	21.9	
124C-D-7	Inner Race	Gold	5-1/2	48.1	
124C-D-7	Outer Race	Gold	4-1/2	39.4	
124C-D-7	Balls	Gold	4	35.0	
142C-D-7	Inner Race	Silver	5	43.8	See Photomicrograph
142C-D-7	Outer Race	Silver	5	43.8	
142C-D-7	Retainer	Silver	5-1/2	48.1	
142C-D-7	Balls	Gold	3	26.3	
123C-LR-7	Inner Race	Gold	5	43.8	
	Outer Race	Gold	6	52.6	
	Retainer	Silver	14	122.5	
	Balls	Gold	5	43.8	
124C-LR-7	Inner Race	Gold	5	43.8	
	Outer Race	Gold	4	35.0	
	Balls	Gold	5	43.8	
142C-LR-7	Inner Race	Silver	Specimen was ground past center.		
142C-LR-7	Outer Race	Silver	16	140.0	
142C-LR-7	Retainer	Silver	12-1/2	109.4	
142C-LR-7	Balls	Gold	7	61.3	

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Microhardness Tests on Substrate — Load = 500g
Instrument = Kentron Microhardness Tester — Obj. = 50X

Assembly Identification	Nomenclature	Substrate Material	Microhardness		D.P.H.N. Converted to R/C
			Avg. No. Filar Units	D.P.H.N.	
123C-D-7	Inner Race	440C-SS	Lost in Fabrication		
"	Outer Race	440C-SS	188	655	58
"	Retainer	Circle 'C'	209	525	51
"	Balls	440C-SS	172	780	64
124C-D-7	Inner Race	440C-SS	183	690	60
"	Outer Race	440C-SS	182	695	60
"	Balls	440C-SS	171	790	64
142C-D-7	Inner Race	440C-SS	189	645	57
"	Outer Race	440C-SS	180	710	61
"	Retainer	Circle 'C'	208	535	51
"	Balls	440C-SS	172	780	64
123C-LR-7	Inner Race	440C-SS	187	660	58
"	Outer Race	440C-SS	180	710	61
"	Retainer	Circle 'C'	214	500	49
"	Balls	440C-SS	171	790	64
124C-LR-7	Inner Race	440C-SS	186	665	59
"	Outer Race	440C-SS	182	695	60
"	Balls	440C-SS	173	770	63
142C-LR-7	Inner Race	440C-SS	189	645	57
"	Outer Race	440C-SS	183	690	60
"	Retainer	Circle 'C'	212	510	50
"	Balls	440C-SS	174	760	63

NOTE: Each hardness value = average of at least 3 readings

W. G. Grenier 6-27-63
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Inner Race No. 123C-LR-7 Plater = Lea Ronal

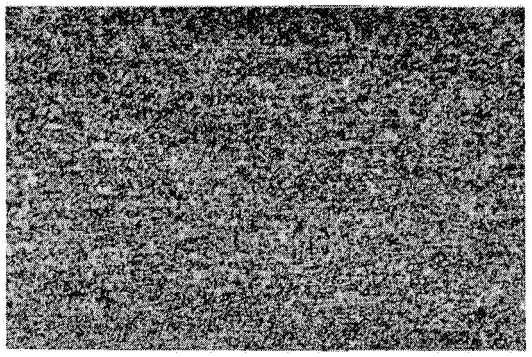


Figure 1 100 X

Typical Inner Race
Substrate Microstructure

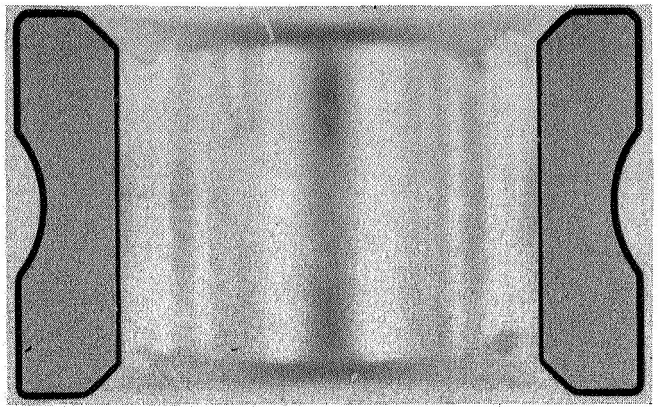


Figure 2 20 X

123C-LR-7, Inner Race, Cross Section

Etch: Picral - HCl
Substrate Hardness: R/C - 58
Substrate Material: 440C - Stainless Steel

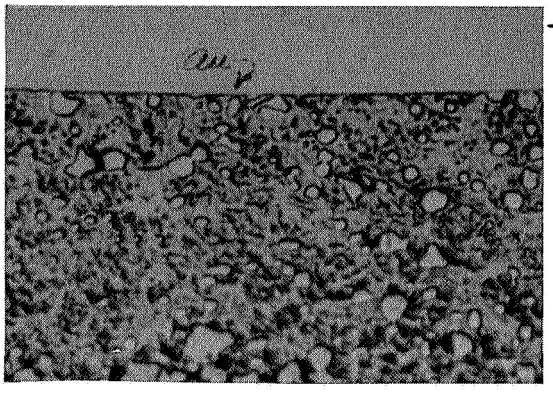


Figure 3 1000 X

Etch: Picral - HCl

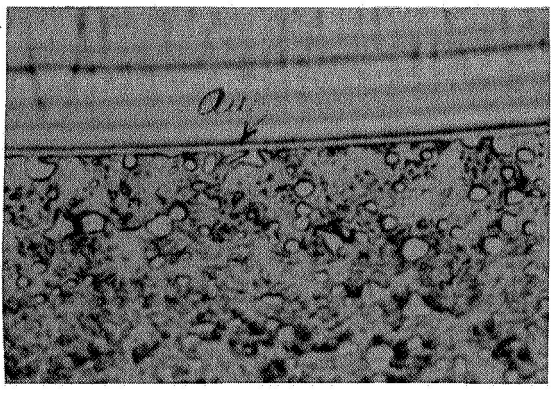


Figure 4 1000 X

2 Step Etch, see Sheet #5

Figures 3 and 4 location = root of raceway.
Band labeled Au, was so determined by color recognition in visual examination.

W. G. Grenier 6-27-63
(Signature) *(Date)*

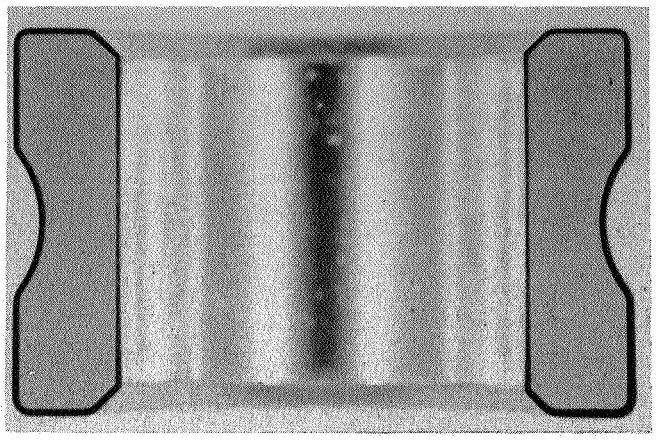
SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Inner Race No. 124C-D-7
Plater & Donovan



R/C -60
Au plated on
440 C stainless

Figure 5-1246-D-7 20 X

Inner Race, Cross Section
Etch: Picral - HCl

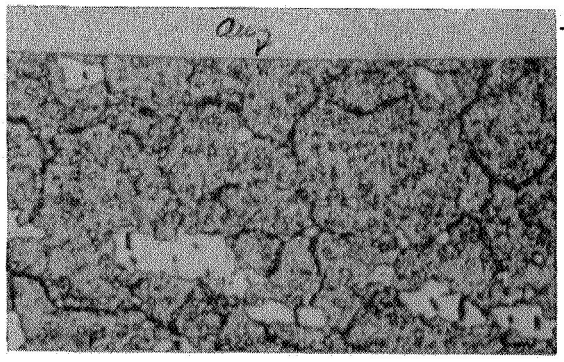


Figure 6 1000 X

Etch: Picral - HCl

←Ni→

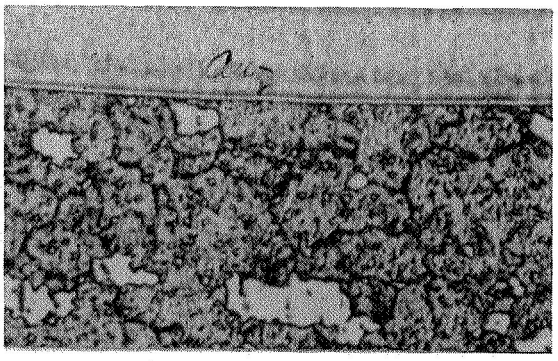


Figure 7 1000 X

Etch: 2 step - see sheet #5

Figures 6 & 7 location = root of raceway.

Typical of Au plate condition.

Au determined by color recognition in visual microscopic examination.

W. G. Grenier 6-28-63
(Signature) *(Date)*

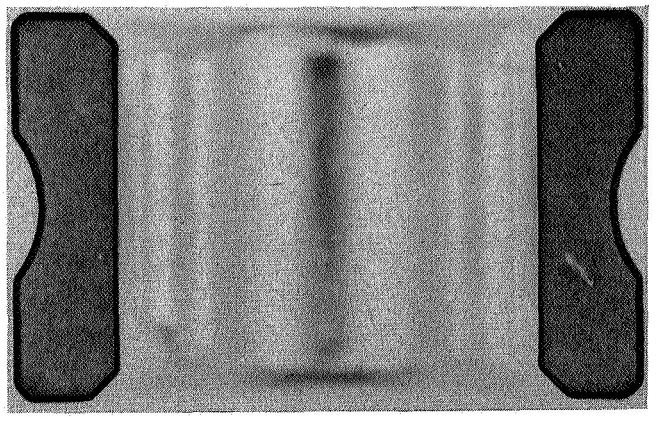
SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Inner Race No. 124C-LR-7
Plater = Lea Ronal



Au plated on
440 C stainless

Figure 8 20 X

Inner Race, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-59

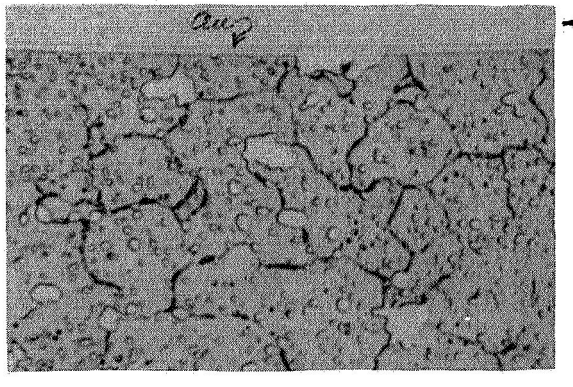


Figure 9 1000 X

Etch: Picral - HCl

←Ni→

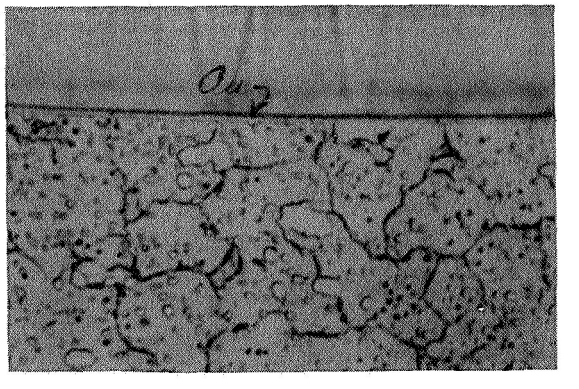


Figure 10 1000 X

Etch: 2 step - see sheet #5

Figures 9 & 10 location = root of raceway

Typical Au plate condition

Au determined by color recognition in visual microscopic examination.

W. G. Grenier 6-28-63
(Signature) (Date)

SERVICE REPORT

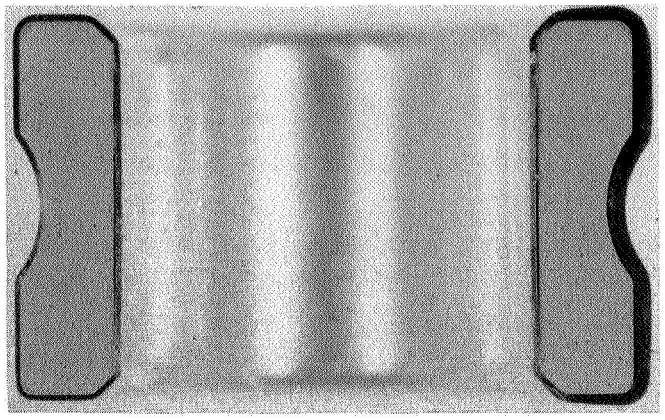
STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

Metallography of Inner Race No. 142C-D-7

DATA: Plater = Donovan



Silver plated race

Figure 11 20 X

Inner Race, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-57

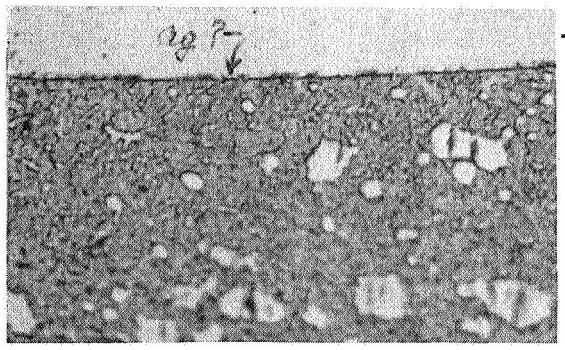


Figure 12 1000 X
Etch: Picral - HCl

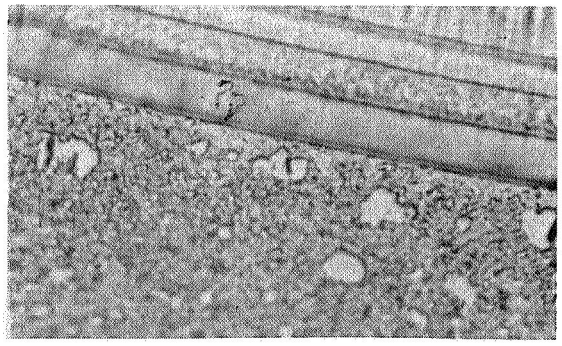


Figure 13 1000 X
Etch: 2 step - see sheet #5

Figures 12 and 13 location = root of raceway.

Band at edge of substrate may be halation effect due to difference in levels of substrate and the protective Ni plate. No Ag plate was discernible as such under visual microscopic examination.

Specimen was examined microscopically with polarized light, blue daylight filter, no filters, and orange-green filters.

2 step etch preferentially attacks the silver, if present.

W. G. Grenier 6-28-63
(Signature) *(Date)*

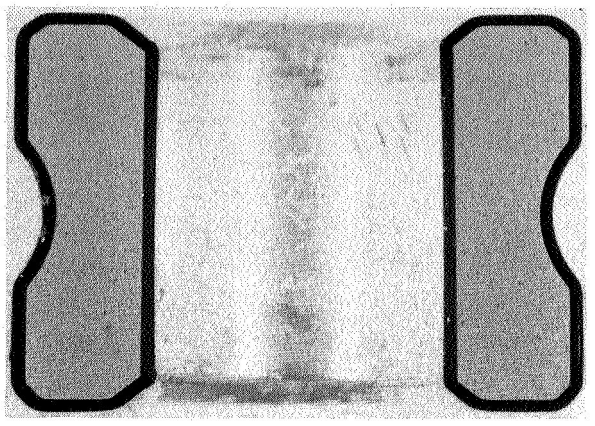
SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Inner Race No. 142C-LR-7
Plater = Lea Ronal



Silver plated race

Figure 14 20 X
Inner Race, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-57

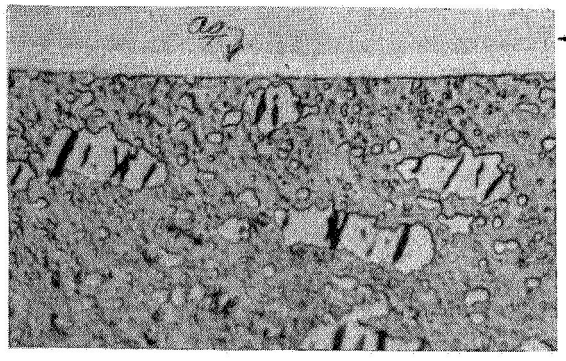


Figure 15 1000 X
Etch: Picral - HCl

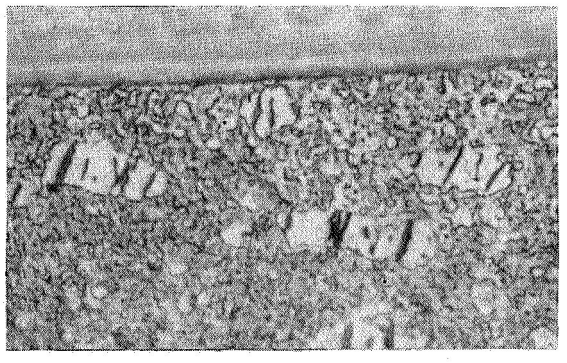


Figure 16 1000 X
Etch: 2 step - see sheet #5

Figures 15 and 16 location = root of raceway.

Wide band of Ag in Figure 15 is due to race being ground well below midpoint, therefore apparent thickness of plate is erroneous.

Two step etch used in Figure 16, preferentially attacked the Ag as well as Ni, therefore no Ag plate is discernible as such.

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(Signature) (Date)

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Outer Race No. 123C-D-7
Plater = Donovan

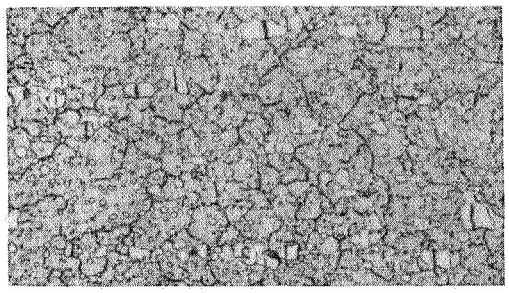

Figure 17 400 X

Typical Outer Race
Substrate Microstructure
Material: 440C Stainless Steel
Etch: Picral - HCl
Substrate Hardness: R/C-58

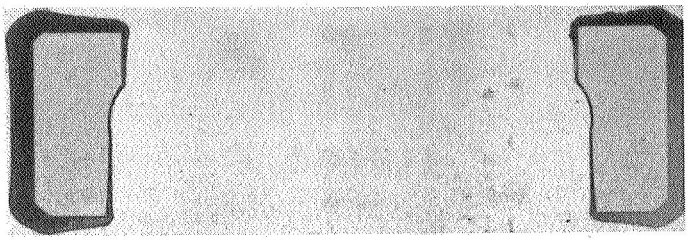

Figure 18 10 X

Outer Race, Cross Section
Etch: Picral - HCl

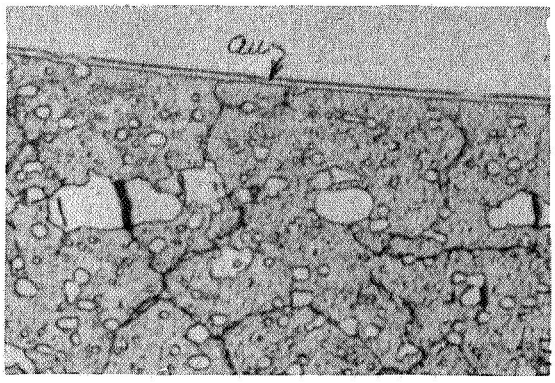

Figure 19 1000 X

Etch: Picral - HCl

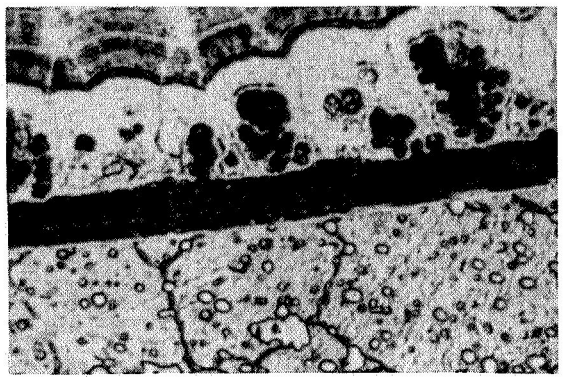

Figure 20 1000 X

Etch: 2 step - see sheet #5

Figures 19 and 20 location = root of raceway.
Au plate is well defined in Figure 19 but obscured by overstretching in Figure 20.

Au plate was determined by color under direct visual microscopic examination.

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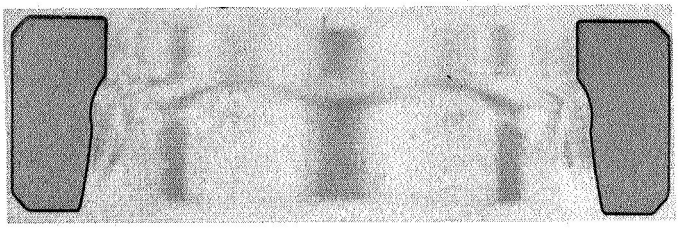
SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36
DATA: Metallography of Outer Race No. 123C-LR-7 Plater = Lea Ronal			



Au plated on
440 C stainless

Figure 21 10 X

Outer Race, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-61

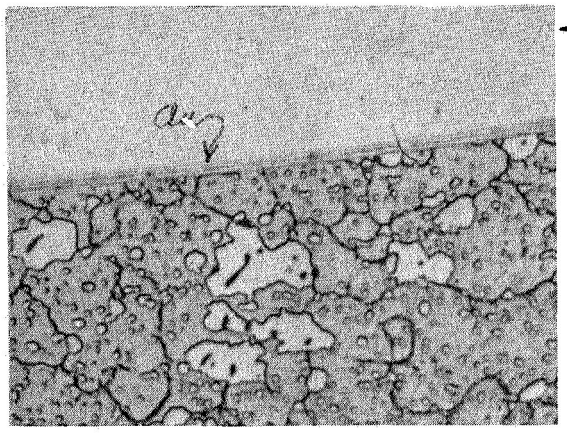


Figure 22 1000 X

Etch: Picral - HCl

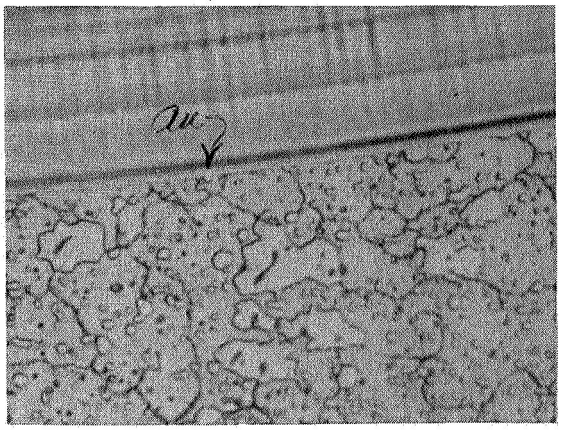


Figure 23 1000 X

Etch: 2 step - see sheet #5

Au plate is striated; but tightly bonded to the substrate.

Au plate was defined as such by color recognition in visual microscopic examination.

Figures 22 and 23 location = root of raceway.

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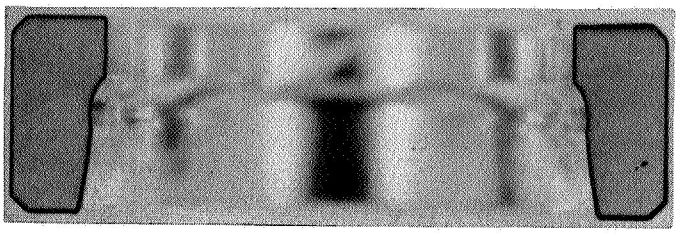
SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Outer Race No. 124C-D-7
Plater = Donovan



Au plated on
440 C stainless

Figure 24 10 X

Outer Race, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-60

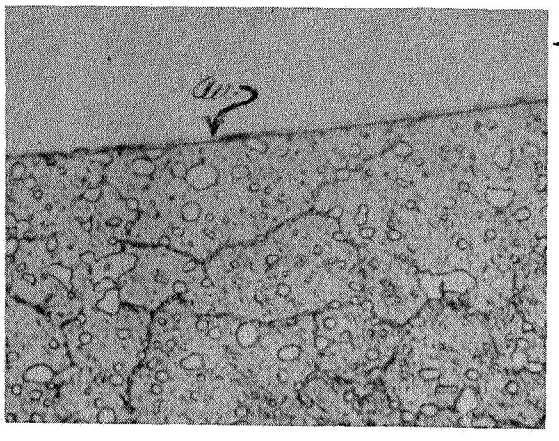


Figure 25 1000 X

Etch: Picral -HCl

←Ni→

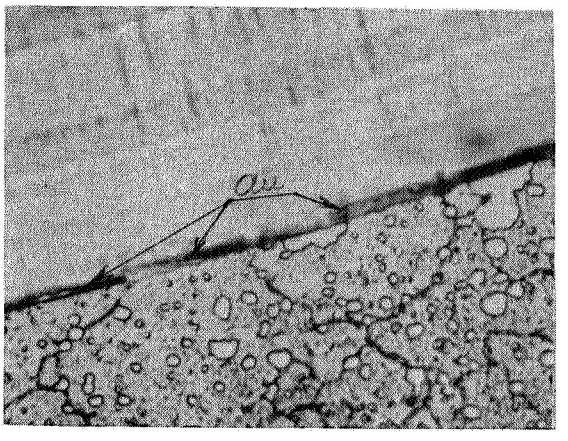


Figure 26 1000 X

Etch: 2 step - see sheet #5

Figures 25 & 26 location = root of raceway.

Au plate in areas designated was defined as such by color recognition.

2nd step etch did not aid in defining Au plate due to excessive attack on Ni plate adjacent to the Au.

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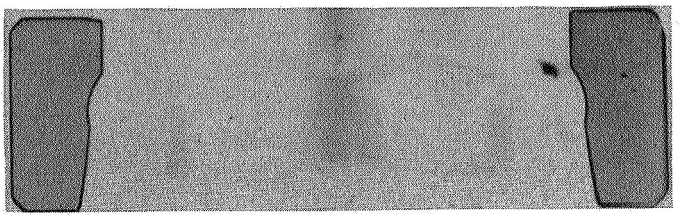
SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

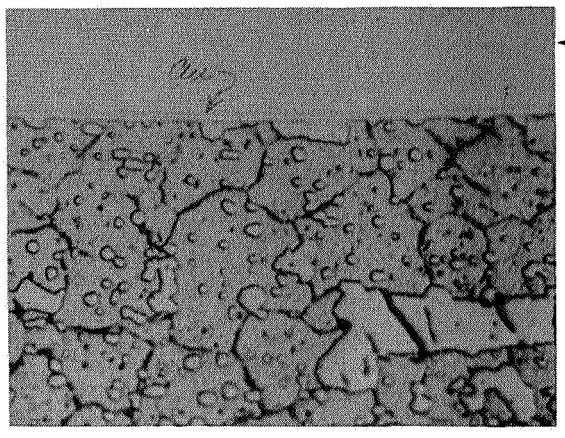
DATA: Metallography of Outer Race No. 124C-LR-7 Plater = Lea Ronal



Au plated on
440 C stainless

Figure 27 10 X

Outer Race, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-60



←Ni→

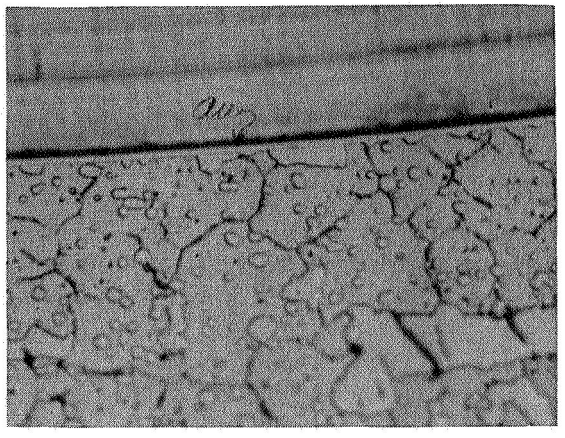


Figure 28 1000 X

Figure 29 1000 X

Figures 28 & 29 location = root of raceway.

Au plate, as defined by color forms tight bond on substrate.

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SERVICE REPORT

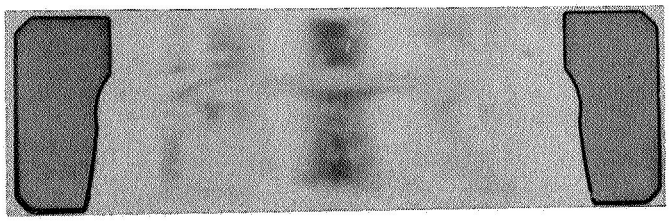
STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Outer Race No. 142C-D-7 Plater = Donovan

Ag plated



Ag plated on 440 C stainless

Figure 30 10 X

Outer Race, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-61

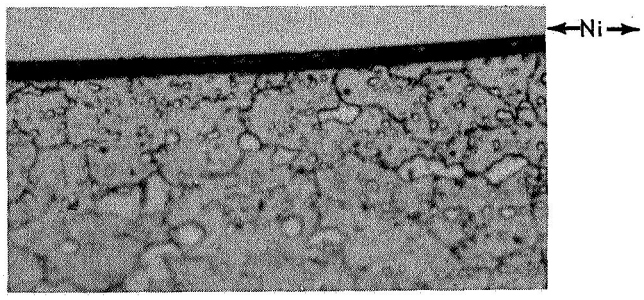


Figure 31 1000 X

Root of Raceway
No discernible Ag plate

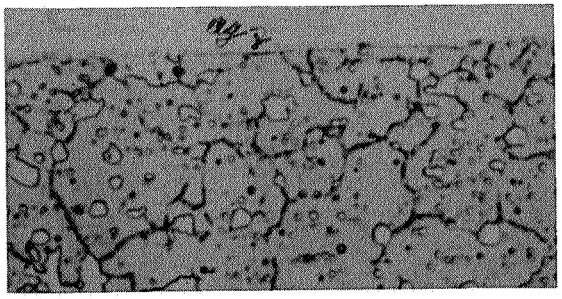
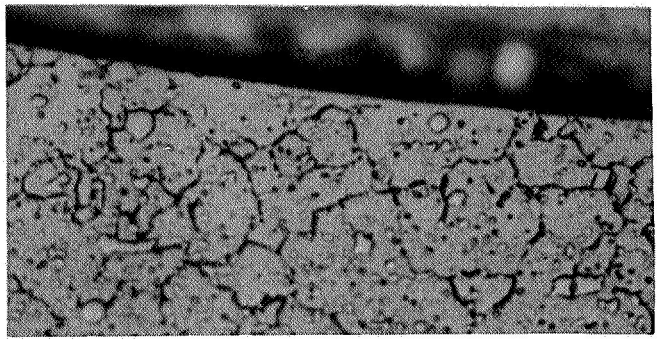


Figure 32 1000 X

Backside of Race
Ag plating discernible

Figures 31 & 32 Etch: Picral - HCl



Halation due to variance in levels of substrate and protective nickel plating.

Etch: 2 step - see sheet #5

Figure 33 1000 X

Location = Root of Raceway

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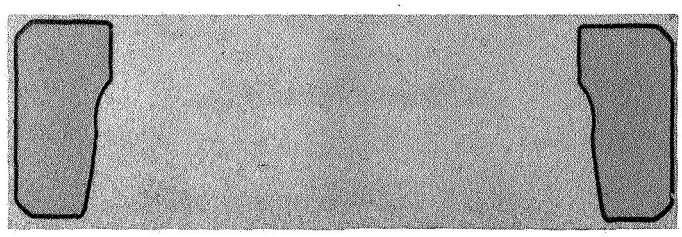
SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Outer Race No. 142C-LR-7 Plater = Lea Ronal



Ag plated on
440 C stainless

Figure 34 10 X

Outer Race, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-60

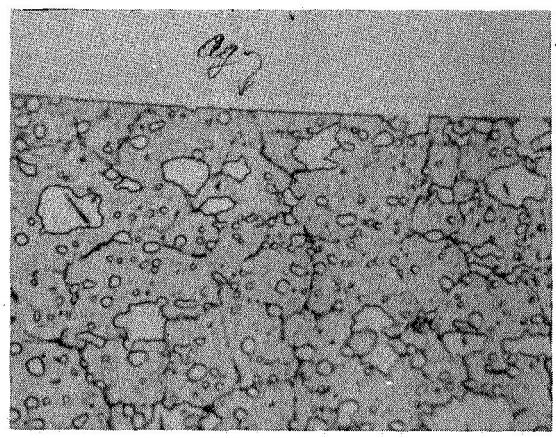


Figure 35 1000 X

Etch: Picral - HCl

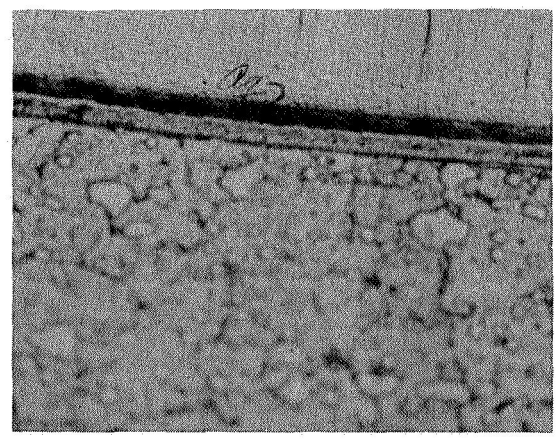


Figure 36 1000 X

Etch: 2 step - see sheet 5

Focus on Ag plate

Figures 35 & 36 location = root of raceway but plating condition is typical of entire specimen.

In Figure 36 note difference in levels of substrate and plated materials.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Retainer Substrate Etch: 4% Nital

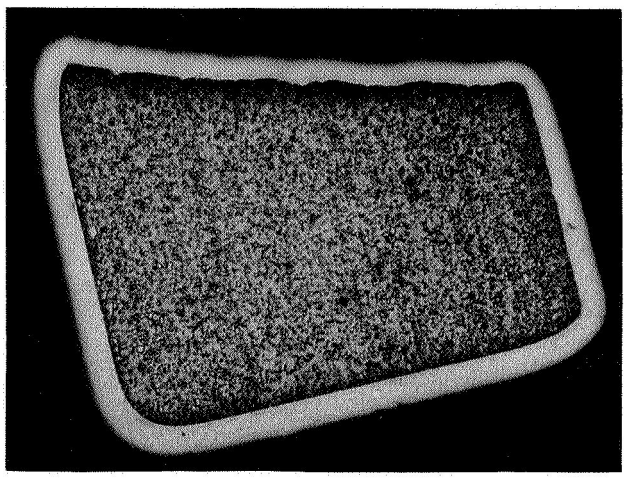

Figure 37 100 X

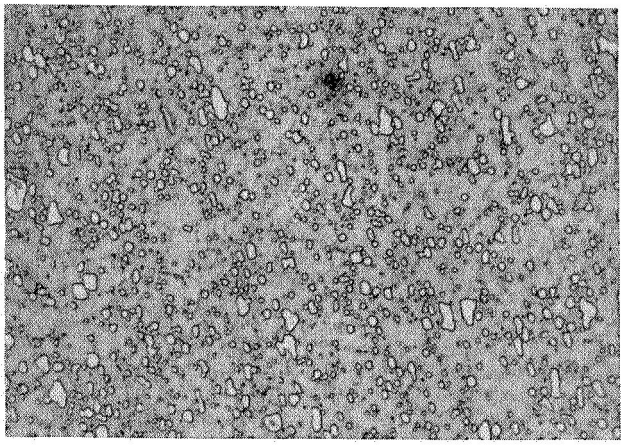

Figure 38 400 X

Figures 37 & 38 show typical retainer substrate microstructure.

Material: Circle "C" steel is classed as a super-high speed steel with good toughness for heavy duty tools.

Nominal composition = 0.77 C, 9 Co, 18.5 W, 4.5 Cr, 2 V, 1.0 Mo, & balance Fe.

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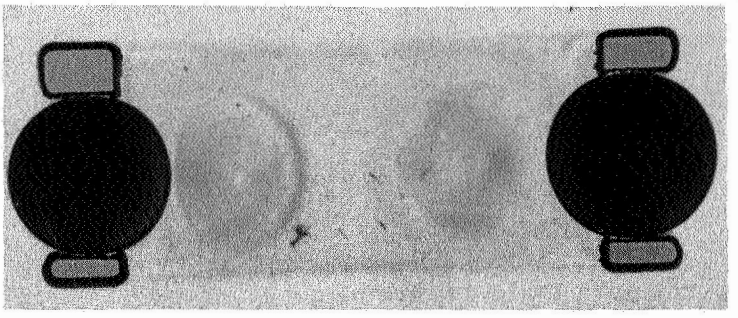
SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Retainer No. 123C-D-7, Plater = Donovan
Etchant Used = 4% Nital



Ag plated on
circle 'C' steel

Figure 39 15 X

Retainer cross section with brass balls in retainer as used by Fabrication Div. for aid in nickel plating over the primary Ag plate.

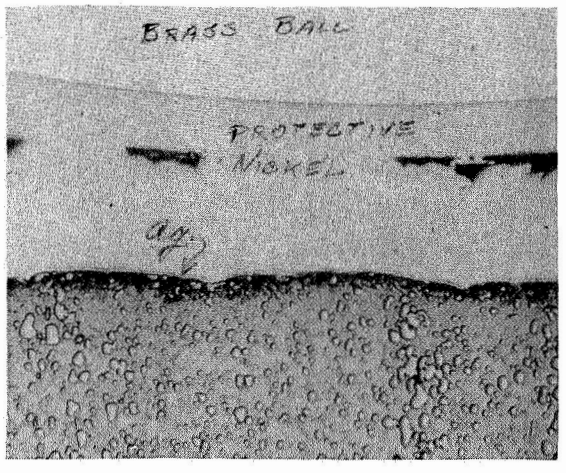


Figure 40 400 X

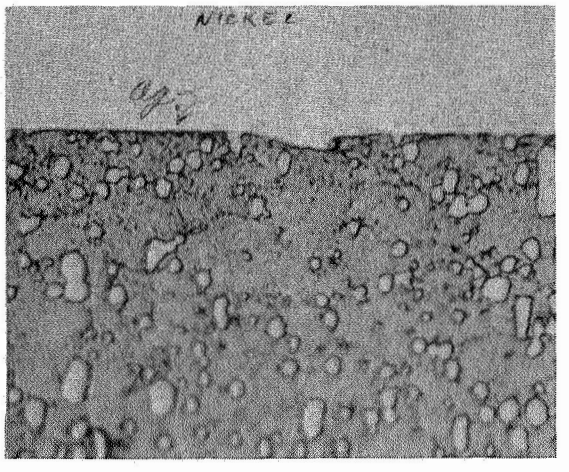


Figure 41 1000 X

Figures 40 & 41 show tight Ag plate in retainer bearing seat.

Substrate hardness: R/C-51.

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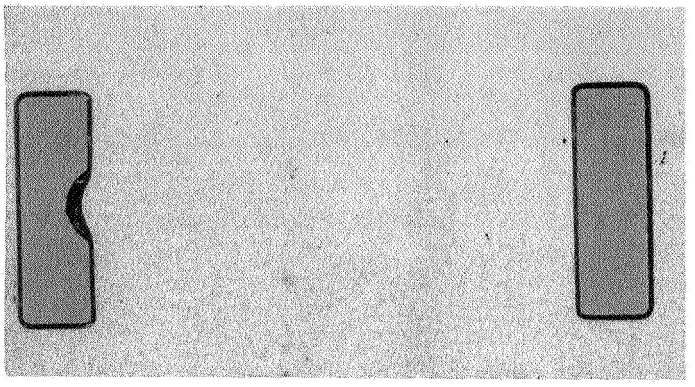
SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Retainer No. 123C-LR-7, Plater = Lea Ronal
Etchant Used = 4% Nital



Ag plated on circle 'C' steel

Figure 42 15 X

Retainer, Cross Section
Substrate Hardness: R/C-49

Figure 43 1000 X

Figure 43 points up integrity of Ag plate.

The apparent thickness of the Ag plate in Figure 43 is caused by the curvature of the bearing seat, as shown in the cross sectional photomacrograph Figure 42.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Retainer No. 142C-D-7, Plater = Donovan
Etchant Used = 4% Nital

Ag plated on circle 'C' steel

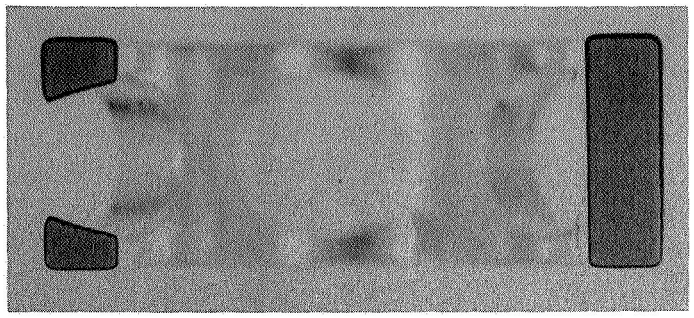

Figure 44 15 X

Retainer, Cross Section
Substrate Hardness: R/C-51

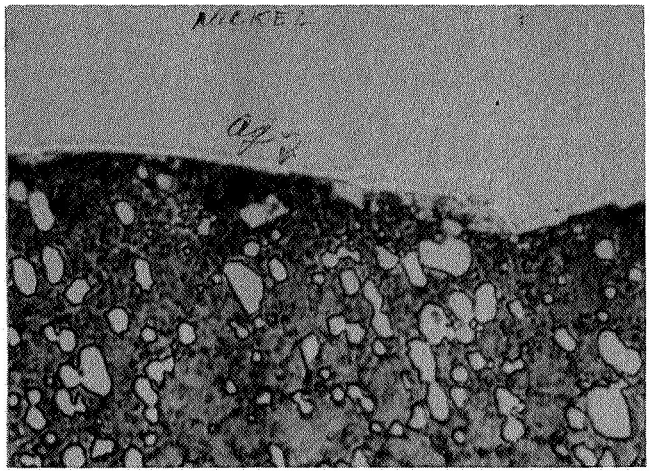

Figure 45 1000 X

Figure 45 shows tightly bonded Ag plate in retainer bearing seat. Ag plate condition is typical of entire specimen.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Retainer No. 142C-LR-7, Plater = Lea Ronal
Etchant Used = 4% Nital

Ag plated on circle 'C' steel

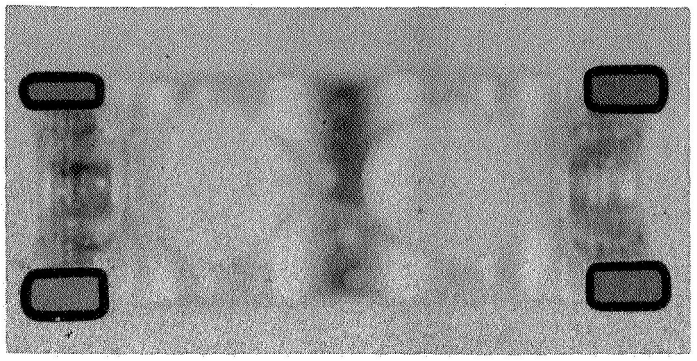

Figure 46 15 X

Retainer, Cross Section
Substrate Hardness: R/C-50

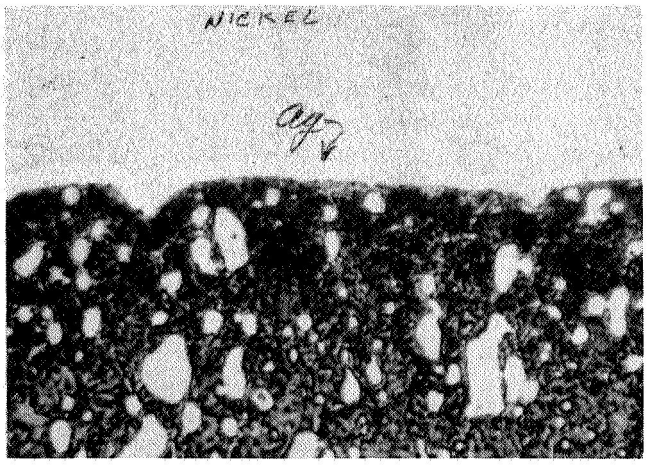

Figure 47 1000 X

Figure 47 shows tightly bonded Ag plate in retainer bearing seat typical of entire specimen.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Bearing Ball Substrate Material
Material: 440C Stainless Steel; Etchant: Picral-Hydrochloric

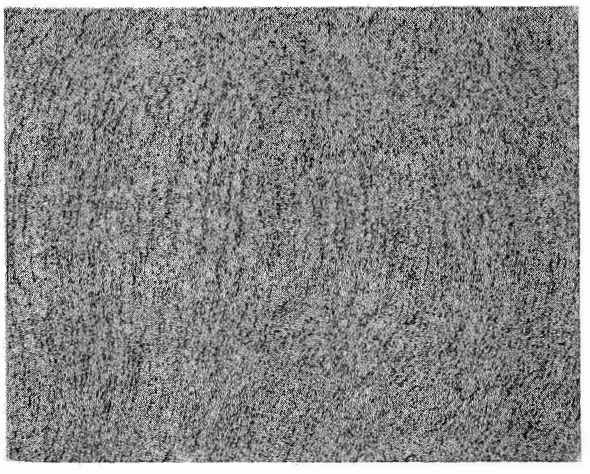

Figure 48 67 X

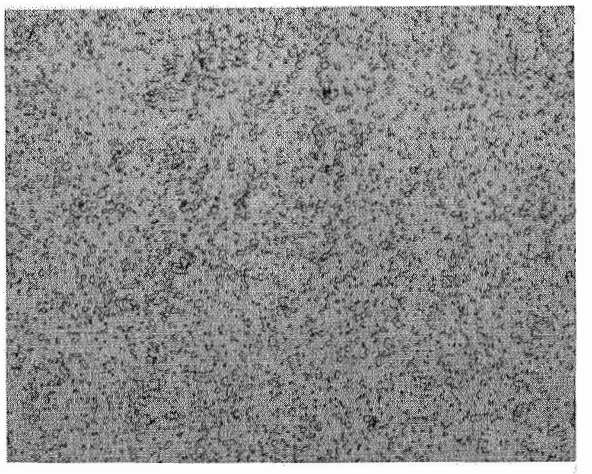

Figure 49 400 X

Bearing Ball Substrate Microstructure

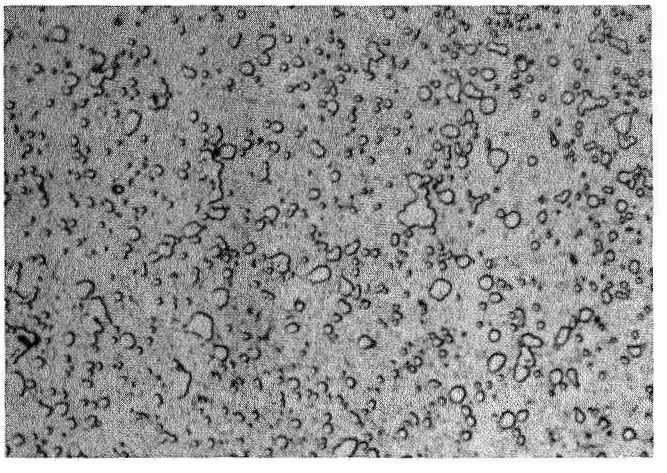

Figure 50 1000 X

R/C-63-64

Shows material, 440C stainless microstructure typical of full hard condition. Undissolved carbides in martensite.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M. R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Bearing Balls No. 123C-D-7. Plater = Donovan

Au plated on
440 C stainless

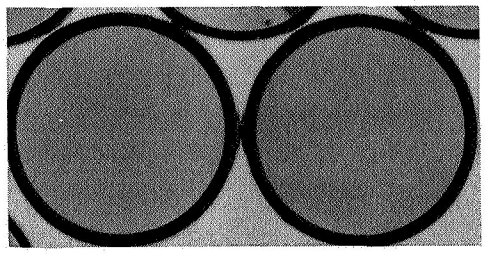

Figure 51 20 X

Bearing Balls, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-64

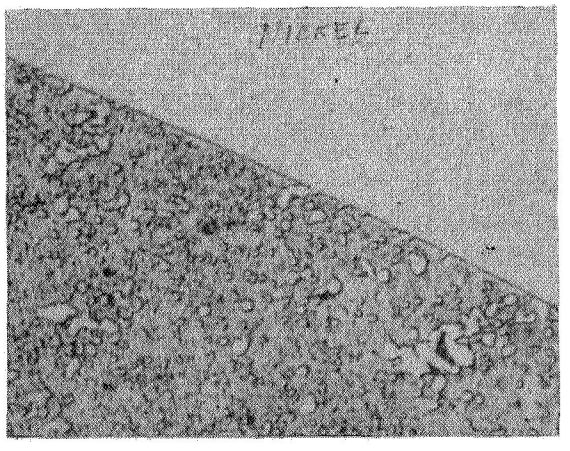

Figure 52 1000 X

Etch: Picral - HCl

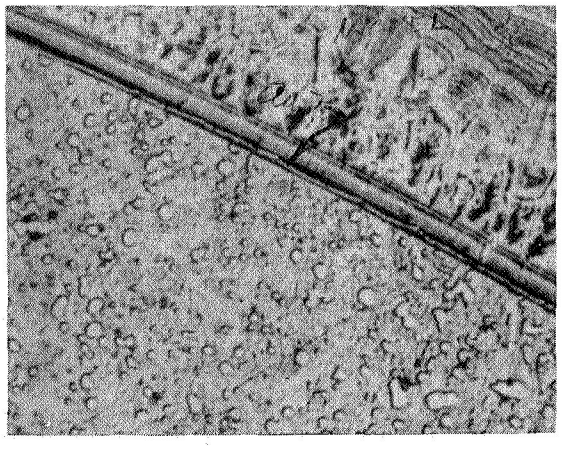

Figure 53 1000 X

Etch: 2 step - see sheet #5

No Au plate was discernible in Figure 52.

In Figure 53 the strata labeled Au?, is so labeled due to occasional color recognition. In this case it is felt that the color could be due to halation. It can not be considered a tight plate, in any case.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Bearing Balls No. 123C-LR-7. Plater = Lea Ronal

Au plated on
440 C stainless

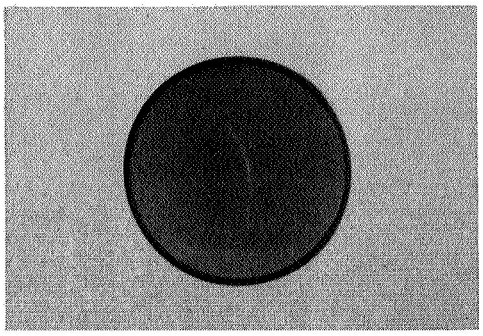

Figure 54 20X

Bearing Ball, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-64

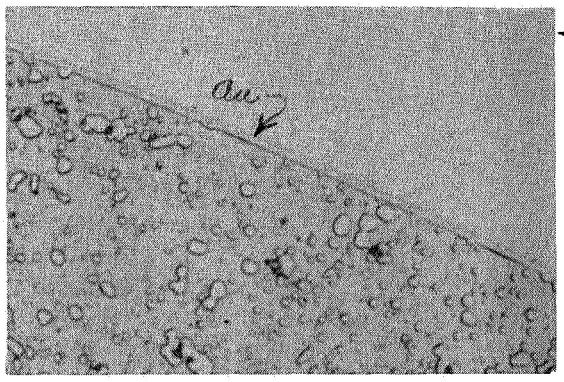

Figure 55 1000X

Etch: Picral - HCl

◄Ni►

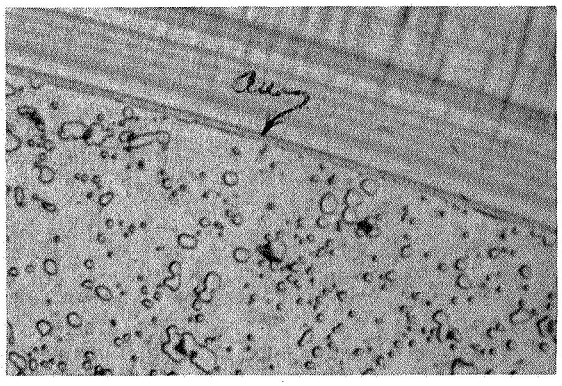

Figure 56 1000X

Etch: 2 step - see sheet #5

Tight Au plate of Figures 55 & 56 are typical.

Other bearing balls originally in mount with one shown in Figure 54, vibrated out of the lucite mount during ultrasonic cleaning in the polishing stage of preparation.

W. G. Grenier 6-29-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M. R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Bearing Balls No. 124C-D-7. Plater = Donovan

Au plated on
440C stainless

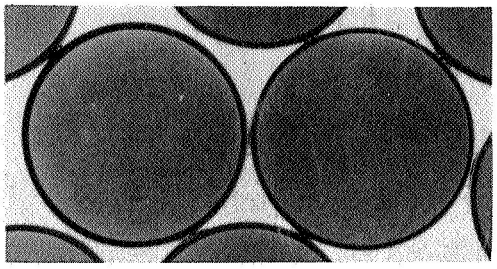

Figure 57 20X

Bearing Balls, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-64

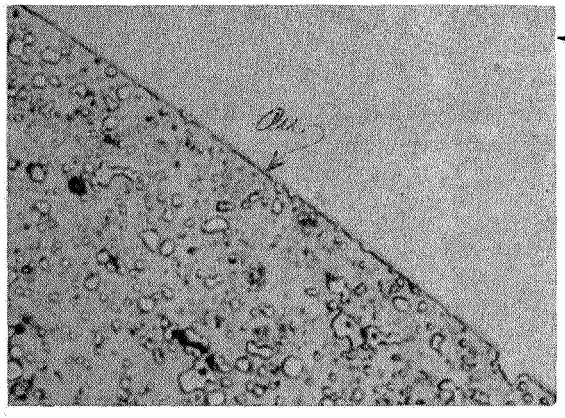

Figure 58 1000X

Etch: Picral - HCl

←Ni→

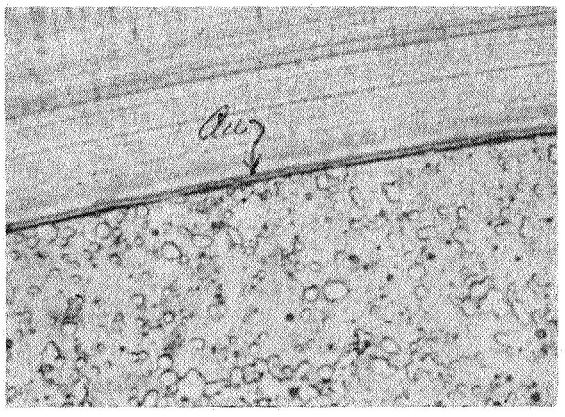

Figure 59 1000X

Etch: 2 step - see sheet #5

Au plate as determined by color recognition is shown in Figure 59 to be less tightly bonded to the substrate than is indicated in Figure 58.

Conditions shown are typical of this set of bearing balls.

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(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Bearing Balls No. 124C-LR-7. Plater = Lea Ronal

Au plated on
440C stainless

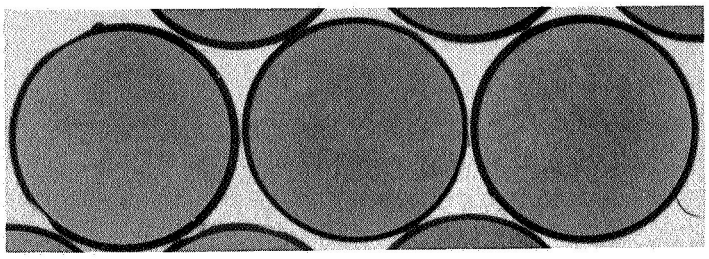

Figure 60 20X

Bearing Balls, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-63

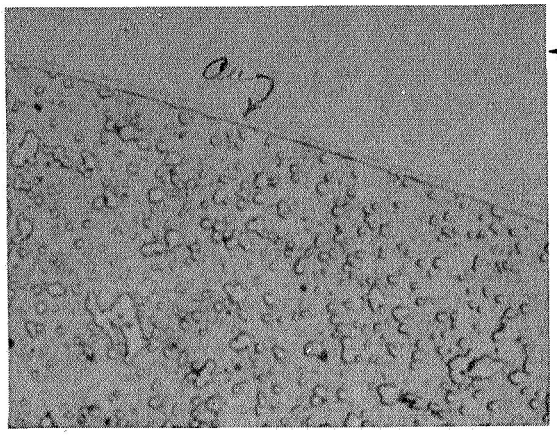

Figure 61 1000X

←Ni→

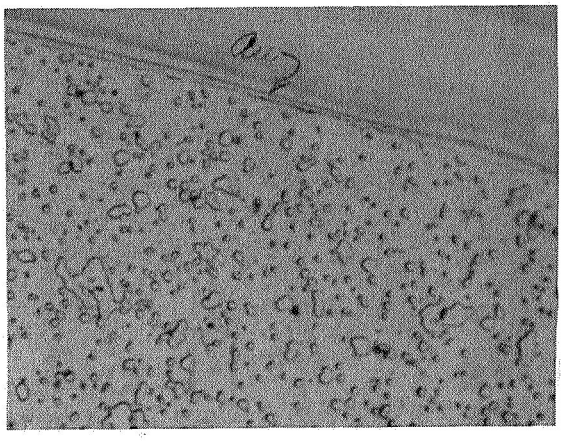

Figure 62 1000X

Etch: Picral - HCl

Etch: 2 step - see sheet # 5

Tight Au plate as determined through color recognition. Typical of this set of bearing balls.

Note nonuniformity of thickness of Au plate.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Bearing Balls No. 142C-D-7. Plater = Donovan

Au plated on
440C stainless

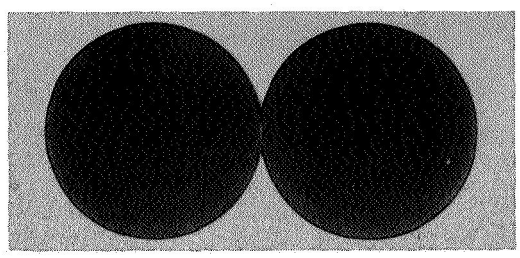

Figure 63 20X

Bearing Balls, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-63

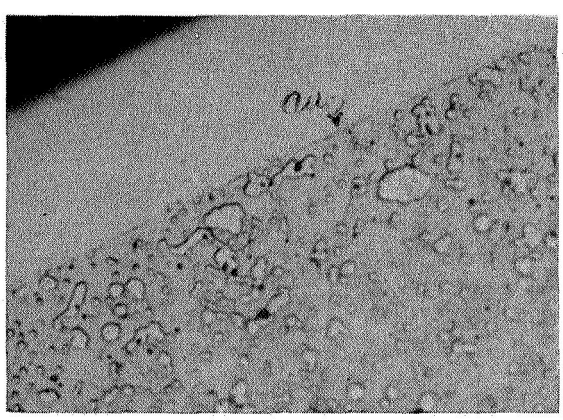

Figure 64 1000X

Etch: Picral - HCl

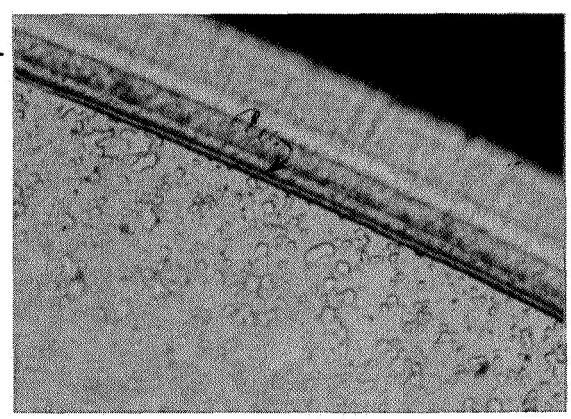

Figure 65 1000X

Etch: 2 step - see sheet #5

In Figure 64 strata labeled Au was so determined by color recognition using no filters on microscope.

In Figure 65 strata labeled Au was so determined by color recognition using polarized light on the object under the microscope.

The Au plate is not tight.

W. G. Grenier 6-29-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Bearing Balls No. 142C-LR-7. Plater = Lea Ronal

Au plated on
440C stainless

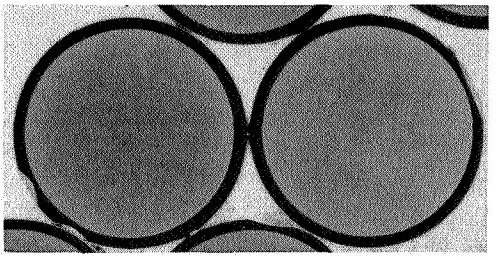

Figure 66 20X

Bearing Balls, Cross Section
Etch: Picral - HCl
Substrate Hardness: R/C-63

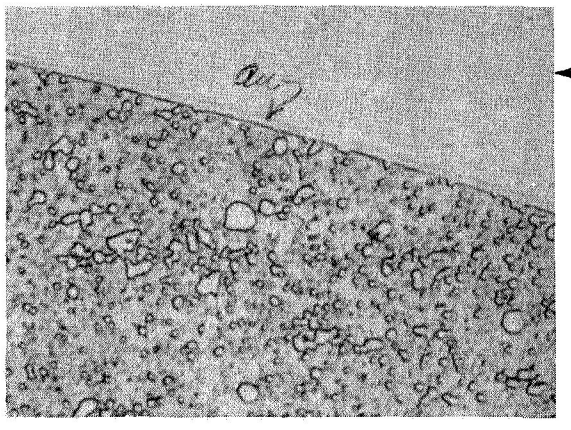

Figure 67 1000X

Etch: Picral - HCl

←Ni→

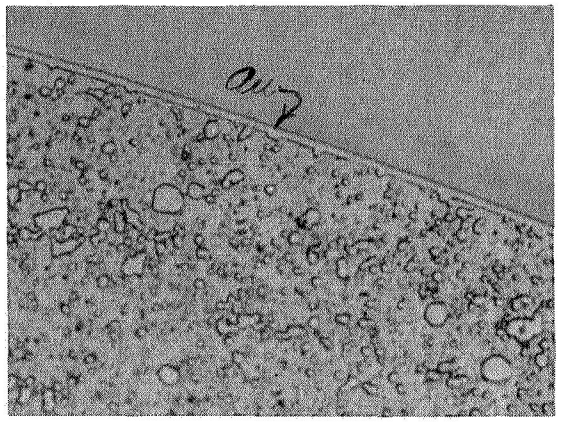

Figure 68 1000X

Etch: 2 step - see sheet #5

Shows typical tight Au plate.

W. G. Grenier 6-29-63
(Signature) *(Date)*

Sect. Head:

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION M.R.63-3

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

CONCLUSIONS:

A visual examination of the photo micrographs shows that, in general, the components plated by Lea Ronal (L-R) have a more uniform plate and appear to be more adherent. The Donovan plated components have a separation between the Au plate and substrate. This is probably caused by etching away the nickel flash on the substrate. The Donovan plate is irregular and the Ag plate is not as thick as the L-R plate, although, the L-R Ag plate is about twice as thick as the Au plate.

It can be concluded on this limited sample that Lea Ronal produced a better Au and Ag plate on ball bearing components. It is felt that the results from this small sample size are insufficient to choose a plater for our components.

Charles E. Vest 7-2-63
(Signature) (Date)

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C. E. Vest	Beltsville	125	Project III Bearings Study	673Y03-13	1200-36

DATE IN	DATE COMPLETED	PERFORMED BY
5-20-63	7-17-63	W. G. Grenier and J. L. Wall

NAME OF TEST

Metallographic Examination

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Ten groups of Au plated bearing balls to be examined for Integrity and thickness of Au plate. Some of the balls in each group have received a protective plating of Ni over the Au. The Ni plating was provided by Fabrication Division, as was the original Au plate.

EQUIPMENT INVOLVED:

Kentron Microhardness Tester, various hand tools, Bakelite ring forms, glass filled epoxy cold mount, wet silicon carbide belt surfacer, Handimet hand polisher, Unitron bench microscope equipped with Filar eyepiece and micrometer stage, slow speed polishing wheels with Automet attachments, various types of polishing clothes and abrasives, Metallurgical Ultrasonic cleaning apparatus, Fisher Vibratory polisher, B & L Metallurgical DM&TR microscope with calibrated Filar micrometer eyepiece, slow speed hand polishing table with gamal abrasive, etching reagents, Unitron metallograph with Polaroid camera attachment, B&L Research Metallograph.

RESULTS:

Plating thickness was uniform within a given lot and time.

Plating integrity appears good.

See Sheet Nos. 5 & 6 for Au plate thickness and substrate hardness data.

See Sheets Nos. 7 & 8 for substrate Microstructure Figs. 1-6 incl.

See Sheets Nos. 9-20 for Metallographic data of Au plating integrity studies, Figures 7-35 incl.

Nickel plating over the Au appears to offer better Au plate delineation and protection than the glass filled epoxy alone.

W. G. Grenier 7-24-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

PROCEDURE: General

Ten lots of 440-C, stainless steel bearing balls, hardened and stress relieved, were plated with Au by Fabrication Division. The only variable, reported, between lots was the plating time. Two groups of Au plated balls from each lot was submitted, by the originator for Au plate integrity and thickness determinations. One group of Au plated balls, from each lot, was also submitted to the Arbor Research Corporation, by the Fabrication Division, for Au plate thickness measurements. It was desired, of the Structural and Mechanical Applications Section, to determine the thickness of the Au plate as related to plating time and the metallurgical integrity of the Au plate. The integrity of the plate was to be compared with that of the platers as reported under Met. Req. No. 63-3, same request number and project. This work is being alone as an aid in determining the feasibility of In House Au plating operations for the Bearings in Vacuum Studies.

Of the balls submitted to the Structural and Mechanical Applications Section, one group from each lot received a nickel plate over the Au, in Fabrication Division, as the standard method of soft material edge preservation during metallurgical sectioning and polishing operations. The other group of balls, from each lot, received no additional nickel plate. The other group was simply mounted in the glass filled epoxy and the mounting medium subsequently compared with the nickel plate method as an edge preserver. Those mounted groups of balls receiving no Ni plate over the Au, were labeled with numbers only, while those from the same lot which received a Ni plate over the Au were labeled with the same number followed by the letter 'A'.

W. G. Grenier 7-19-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

PROCEDURE: Au Plate Thickness Measurement & Metallographic Preparation

The Au plate thickness measurements, as conducted by the Structural and Mechanical Applications Section, are accomplished by use of optical microscope equipped with Filar micrometer eyepieces. The Au plate thickness measurements, as conducted by the Arbor Research Corporation, were accomplished by means of Beta radiation back reflection techniques. A copy of their report was made available by the Fabrication Division and their data is included, as such, in the results in this report.

The mounting, sectioning, polishing, Au plate thickness measurement, and microhardness determination techniques were as described in the procedures in the Service Report on S.R. 1200-36, Met. Req. No. 63-3, dated 6-29-63, with the following exceptions:

1. All bearing balls were mounted in a ground glass and epoxy mix, rather than in lucite. The mix consisted of 3 parts, by weight, of Hysol 2038 epoxy to 2 parts, by weight, of Corning Glass Works Borosilicate Glass No. 7740, ground and screened to pass 90% through U. S. Standard mesh No. 325. Hardener 3404 was added to the glass and base mix in the ratio of 1 part hardener to 16 parts mix, by weight. It was noted, in this case, that not all of the mounts hardened properly. Therefore all specimens were placed in the heat treating furnace and held at 200°F for twenty four hours or until hard. During the actual polishing operations, soft spots were still encountered in the mounts, making final polishing extremely difficult. This indicates that great care must be taken to ensure that all of the hardener is thoroughly blended with the glass and base mix.

2. Extra, unmounted balls, from each lot were measured with micrometer calipers,

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

PROCEDURE: Metallographic Preparation Contd.

for primary diameter determination, rather than those balls actually mounted.

3. The Fisher Vibratory polisher was used to accomplish the final polish required for the Au plate thickness measurements and microhardness determination. The polish was accomplished using Gamal abrasive on silk, with the vibration setting at 5 for one hour. This produced an excellent surface for the foregoing, but the scratches were still too severe for metallographic purposes. Therefore, the same repolishing procedure as described in the above report was employed.

4. Photomicrographs of the substrate microstructure were prepared at various magnifications. However, those of the Au plated edges were all prepared at one thousand (1000) diameters.

5. No second step etch was employed.

6. Some additional photomicrographs of specimen No. 8-A, were prepared, using the new B & L Research Metallograph.

The apparent roughness of the Au plate exterior surface of those specimens having no protective nickel plate, could be due to any of the following:

1. Polishing drag-out, i.e., the epoxy did not form a tight enough bond to hold the soft Au plate in place.

2. Slight rounding of the edge combined with minute erosion.

3. Abrasion by the ground glass particles in the epoxy, either during mounting or as particles of glass adjacent the Au are torn out during grinding and polishing. This would be indicative of a poor mount.

W. G. Grenier 7-20-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Average Au Plate Thickness and Substrate Hardness as Determined by J. L. Wall

Specimen No.	Au Plating Time Minutes	Au Plate Thickness		Substrate Hardness			Remarks
		F.U.	Ins. $\times 10^6$	F.U.	D.P.H.N.	Convert R/C	
1	4	2.3	20	170	800	64	Note: The width of one filar hair is approximately 2 F.U.
1-A	4	2.3	20	173	770	63	
2	6	2.5	22	173	770	63	
2-A	6	3.0	26	174	760	63	
3	8	4.3	37	174	760	63	
3-A	8	4.0	35	173	770	63	
4	10	6.0	52	172	780	63	
4-A	10	4.5	39	173	770	63	
5	12	6.2	54	174	760	63	
5-A	12	6.3	55	172	780	63	
6	20	13.8	121	171	790	64	Extremely rough plate edges
6-A	20	12.4	108	173	770	63	
7	30	13.8	121	176	740	62	
7-A	30	12.5	109	171	790	64	
8	60	32.0	280	175	755	62	
8-A	60	30.0	262	169	805	64	
9	4	2.6	23	177	735	61	
9-A	4	2.5	22	172	780	63	
10	10	5.2	46	169	805	64	
10-A	10	7.0	61	170	800	64	

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(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Au Plate Thickness as Determined by Arbor Research Corp. on their Beta Scope

Plating Time (minutes)	Average Au Plate Thickness Ins. $\times 10^6$
4	17
6	26
8	38
10	45
12	52
20	116
30	111
60	206

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(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Substrate Material

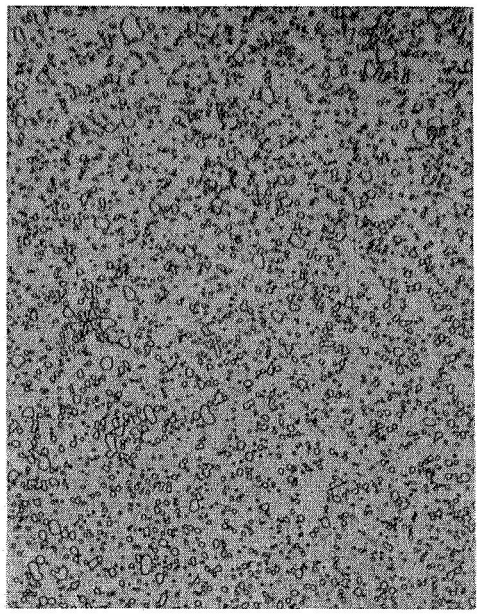

Figure 1 400X

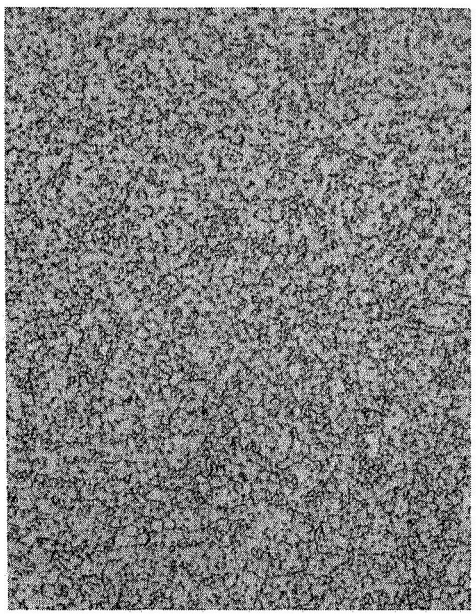

Figure 2 400X

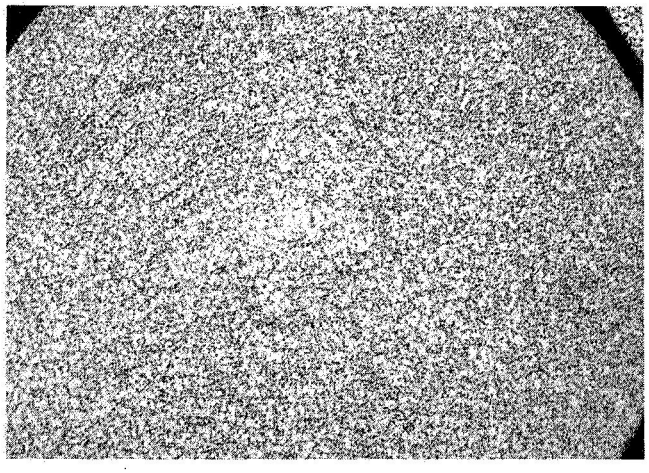

Figure 3 67X

Material = 440C Stainless
Hardness = R/C 61-64 inc.
Etch = Alcohol - 100 ml
HCl - 5 ml
Picric Acid - 2 ml

Figures 1-3 show typical microstructure of substrate.

W. G. Grenier 7-22-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Substrate Material

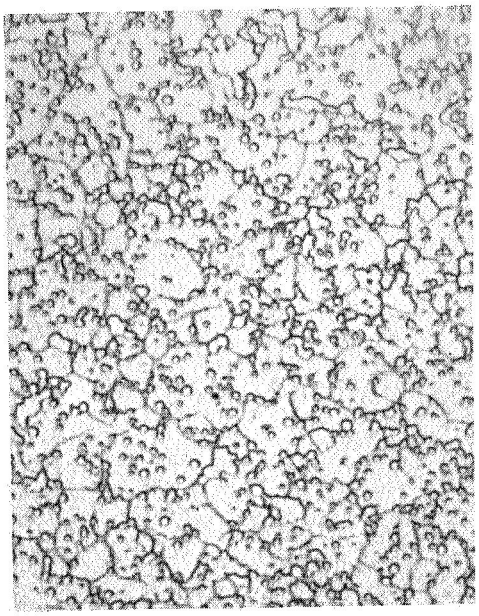

Figure 4 1000X

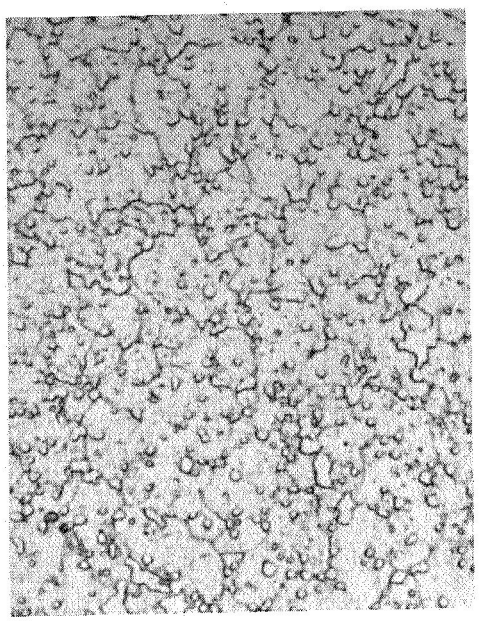

Figure 5 1000X

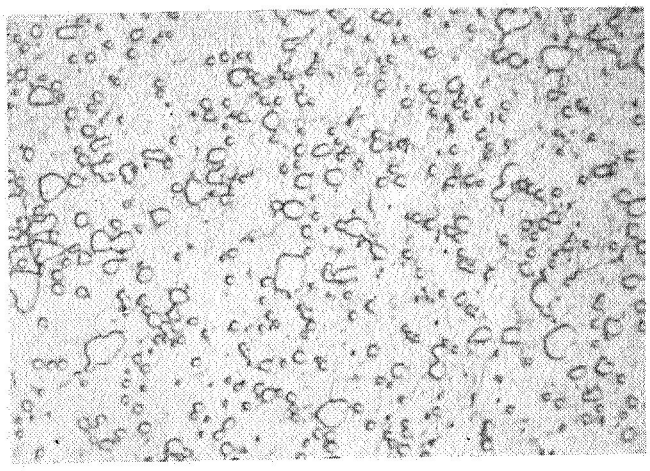

Figure 6 1000X

Material = 440C Stainless
Hardness = R/C 61-64
Etch = Alcohol-100 ml
HCl- 5 ml
Picric Acid- 2 ml

Micrographs showing typical microstructure of substrate.

W. G. Grenier 7-22-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Au Plating Integrity Photomicrographs at 1000 Diameters

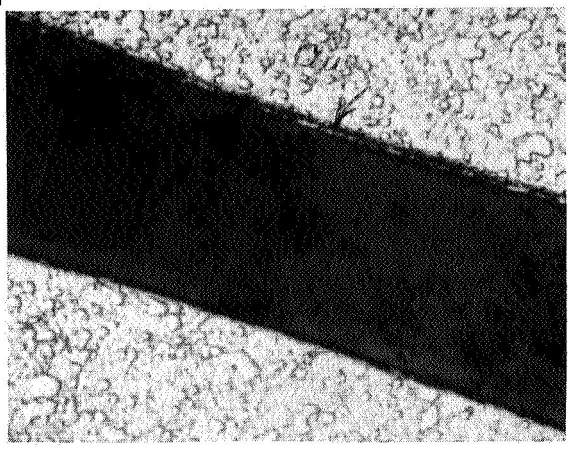

Figure 7

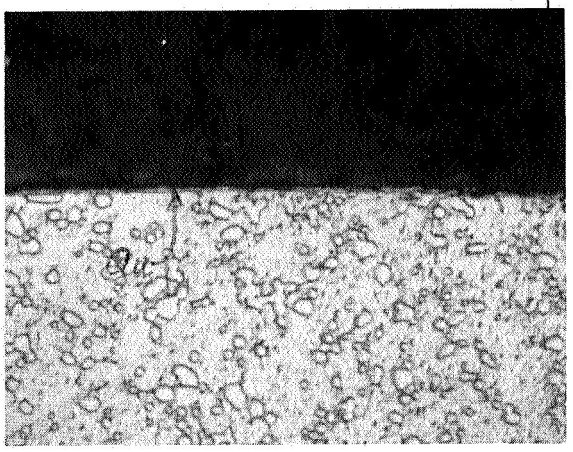

Figure 8

Specimen No. 1, as mounted in glass filled epoxy with no protective Ni plating over the Au.

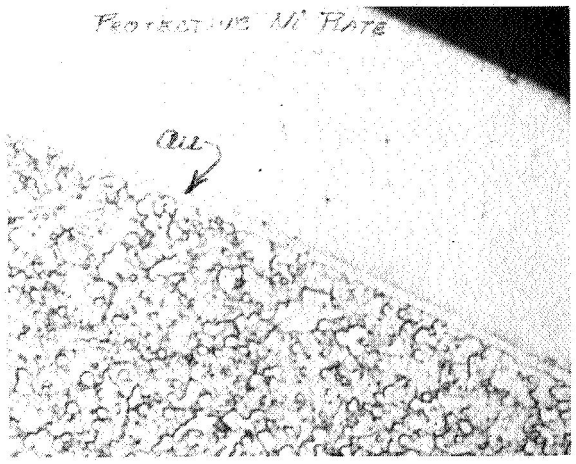

Figure 9

Figures 7-9

Substrate Material = 440C
Substrate Hardness = R/C 63-64
Substrate Etch. = Picral - HCl
Au Plating Time = 4 Minutes
Au Plating Thickness = Approx. 20×10^{-6} in.

Micrographs indicate that the Au plate has tight bond with substrate.

Specimens shown were polished past balls major diameter, therefore Au plate thickness shown is meaningless.

Specimen No. 1-A

Same as above balls with a protective Ni. plate. Note the improved Au plate delineation.

W. G. Grenier 7-22-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Au Plating Integrity. Photomicrographs at 1000 Diameters

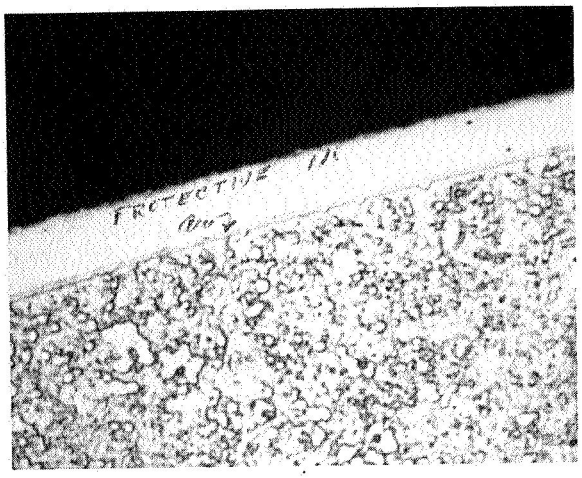

Figure 10

Specimen No. 2

Au plated balls mounted in glass filled epoxy with no protective Ni plating over the Au

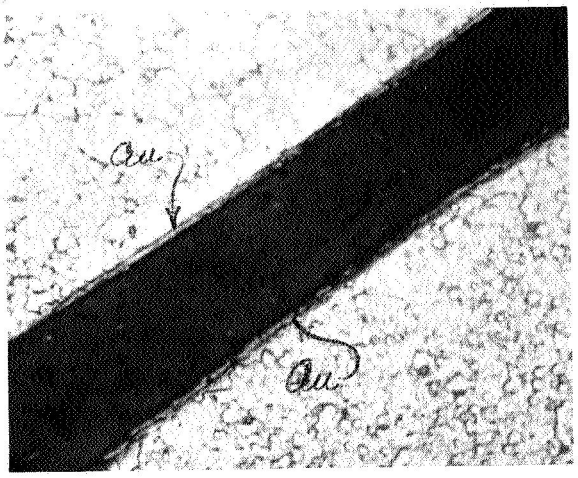

Figure 11

Specimen No. 2-A

Same Au plated balls as Fig. 10, but with a protective Ni plating over the Au. Slight improvement in Au delineation.

Figures 10 & 11

Substrate Material = 440-C
Substrate Hardness = R/C 63
Substrate Etchant = Picral - HCl
Au Plating Time = 6 minutes
Au Plating Thickness = Specimen No. 2 = 22×10^{-6} in.
Specimen No. 2-A = 26×10^{-6} in.

Micrographs indicate that the Au plate has tight metallurgical bond with the substrate.

W. G. Grenier 7-22-63
(Signature) (Date)

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Au Plating Integrity. Photomicrographs at 1000 Diameters

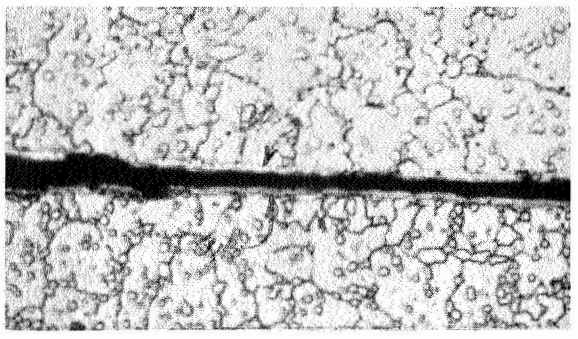

Figure 12

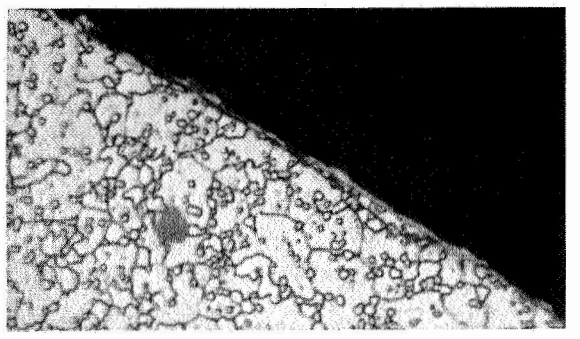

Figure 13

Specimen No. 3, as mounted in glass filled epoxy with no protective Ni plating over the Au.

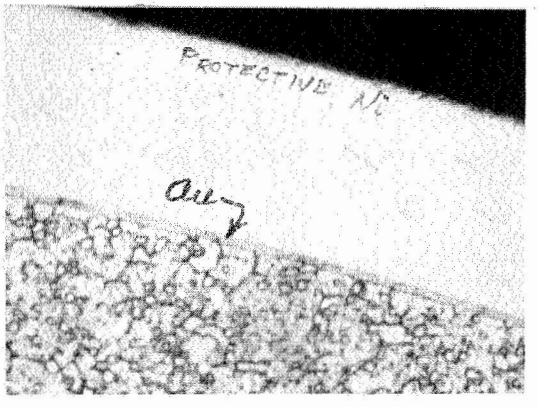

Figure 14

Figures 12-14

Substrate Material = 440-C
Substrate Hardness = R/C-63
Substrate Etch. = Picral - HCl
Au Plating Time = 8 minutes
Au Plating Thickness = 35-37 x 10^{-6} in.

Specimen No. 3-A

Same Au plated balls as above but with a protective Ni plate over the Au. Note the apparent improvement in cleanness of the Au and in its delineation.

Above photomicrographs indicate a tight metallurgical bond between the Au plate and substrate.

W. G. Grenier 7-23-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Au Plating Integrity. Photomicrographs at 1000 Diameters

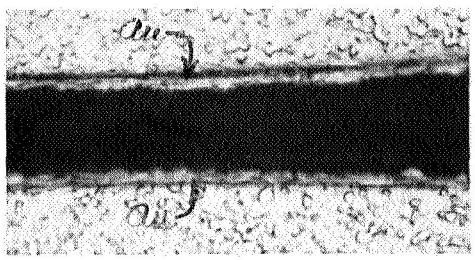

Figure 15

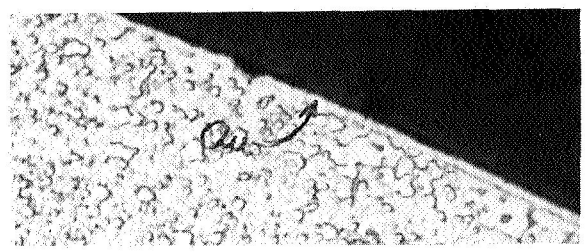

Figure 16

Specimen No. 4, as mounted in glass filled epoxy only.

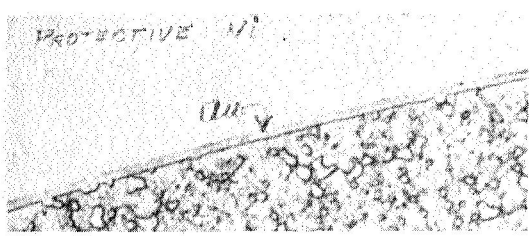

Figure 17

Specimen No. 4-A

Same Au plated balls as above but with a protective Ni plating over the Au. Note improved delineation.

Figures 15-17

Substrate Material = 440C Stainless
Substrate Hardness = R/C-63
Substrate Etch. = Picral - HCl
Au Plating Time = 10 minutes
Au Plating Thickness = 34-52 x 10^{-6} in.*

Above photomicrographs indicate a tight metallurgical bond between the Au plate and the substrate.

*The Au plate appeared to be considerably thicker on those bearing balls which had no protective nickel plating. The average apparent thickness on the Specimen No. 4 balls was 52 x 10^{-6} inches and the plate thickness on the Specimen No. 4-A balls was 39 x 10^{-6} inches. This could be due to slight rounding of the Au edge in those cases where no protective nickel was used or to the activation and cleaning processes used in preparing the Au plated balls for the subsequent nickel plate.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Au Plating Integrity. Photomicrographs at 1000 Diameters

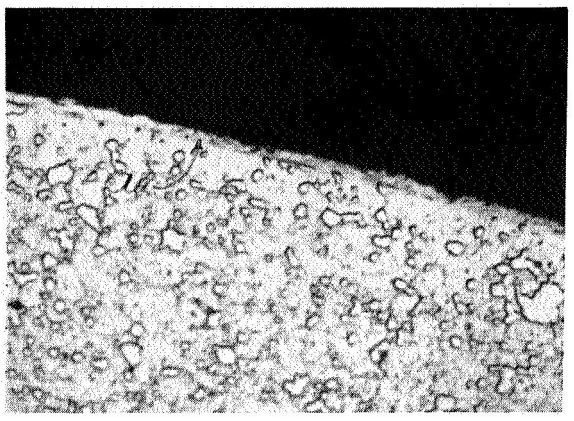

Figure 18

Specimen No. 5

Au plated ball as mounted in glass filled epoxy with no protective nickel plating over the Au plate.

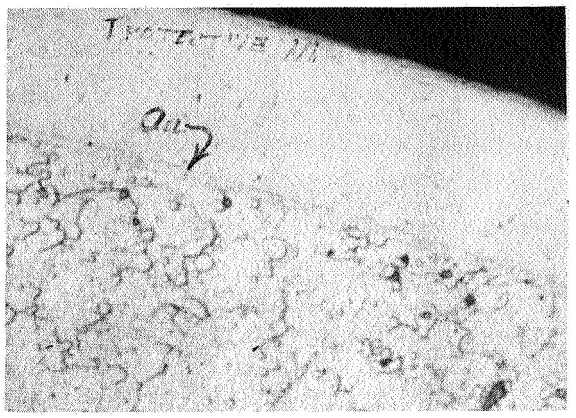

Figure 19

Specimen No. 5-A

Same Au plated balls as Figure 18 but with a protective nickel plating over the Au plate.

Above photomicrographs indicate a tight metallurgical bond exists between the Au plate and the substrate.

Figures 18 & 19

Substrate Material = 440C Stainless Steel
Substract Hardness = R/C-63
Substract Etch. = Picral - HCl
Au Plating Time = 12 minutes
Au Plating Thickness = 51-54 x 10^{-6} inches

See sheet No. 4 of this report for the discussion on roughness of the Au plate.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Au Plating Integrity. Photomicrographs at 1000 Diameters

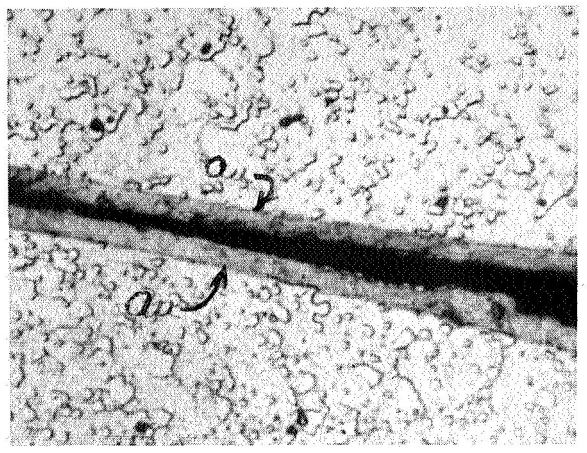

Figure 20

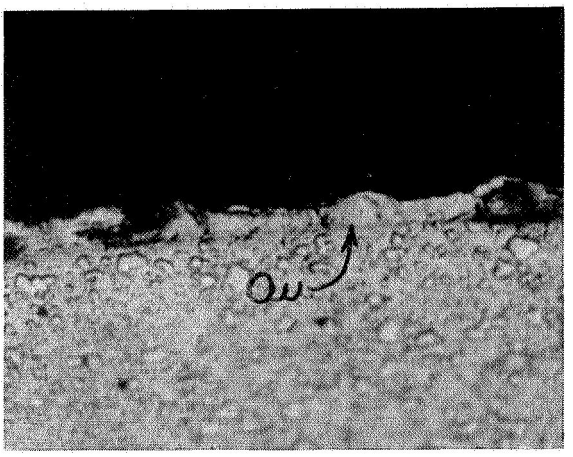

Figure 21

Specimen No. 6

Au plated bearing balls mounted in glass filled epoxy with no protective Ni plate over the Au. Note the relative cleanness of the Au plate edge in Figure No. 20, where two balls offer some protection to each other as compared to the single edge shown in Figure No. 21. Some edge rounding is in existence.

See sheet No. B of this report for a discussion on roughness of the Au plate surface.

Specimen No. 6 Au plate thickness $= 125 \times 10^{-6}$ inches
Specimen No. 6-A Au plate thickness $= 119 \times 10^{-6}$ inches.

See Note * on sheet No. 14 of this report for discussion on discrepancies in Au plate thickness between balls with and without protective Ni plating.

Above photomicrographs indicate tight Au plate.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Au Plating Integrity
Photomicrographs at 1000 Diameters

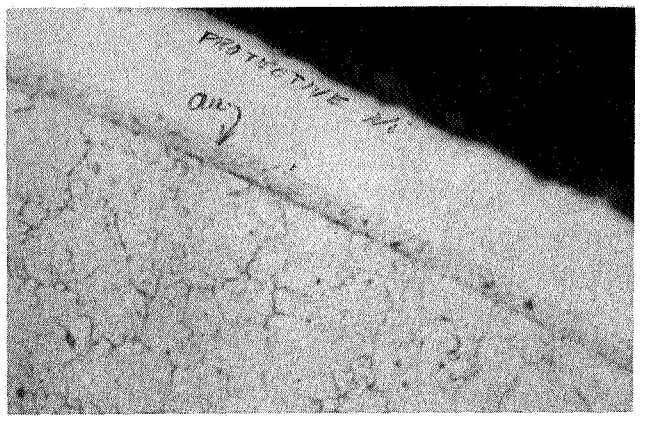

Figure 22 Specimen No. 6-A

Same lot of Au plated balls as is shown in Figures Nos. 20 & 21, but with a protective nickel plating over the Au. Note the cleanness of the Au plate, which is typical of nickel plated specimens.

See Sheet No. 8 of this report for a discussion on apparent roughness of the Au plate.

See * Note on sheet No. 14 of this report for a discussion on discrepancies in the Au plate thickness between balls with and without protective Ni plating.

Figures No. 20-22
Substrate Hardness = R/C 63-64
Substrate Material = 440-C Stainless Steel
Substrate Etch = Picral – HCl
Au plating time = 20 minutes
Au plating thickness = Spec #6 = 125×10^{-6} ins., Spec. #6-A = 119×10^{-6} ins.

Figures Nos. 20-22 show tightly bonded Au plate.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Plating Integrity
Photomicrographs at 1000 Diameters

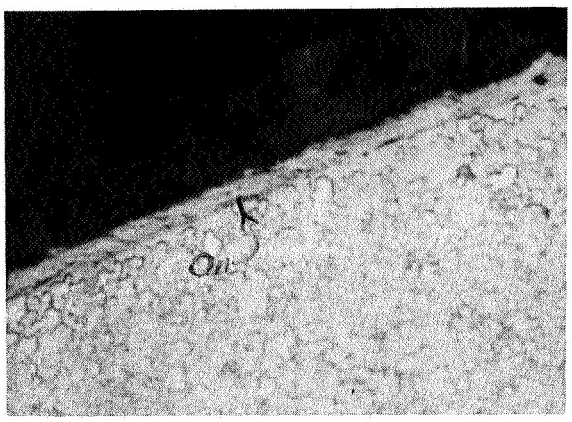

Figure 23 Specimen No. 7

Au plated balls, mounted in glass filled epoxy with no protective Ni plating over the Au.

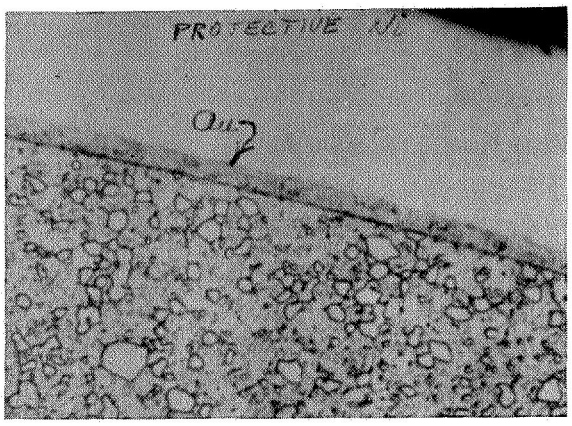

Figure 24 Specimen No. 7-A

Same lot of Au plated balls as Fig. 23, but with a protective Ni plating over the Au.

Above photomicrographs indicate tightly bonded Au plate.

Figures Nos. 23 & 24

Substrate Material = 440-C Stainless Steel
Substrate Hardness = R/C 62-64
Substrate Etch = Picral – HCl
Au plating time = 30 minutes
Au plating thickness = Spec. #7 = 121×10^{-6} inches, Spec. #7-A = 109×10^{-6} inches.

See sheet No. 6 of this report for a discussion on apparent roughness of Au plate.

See * Note on sheet No. 14 of this report for a discussion on the apparent discrepancies in the Au plate thickness between those balls with and without a protective Ni plating.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Plating Integrity
Photomicrographs at 1000 Diameters

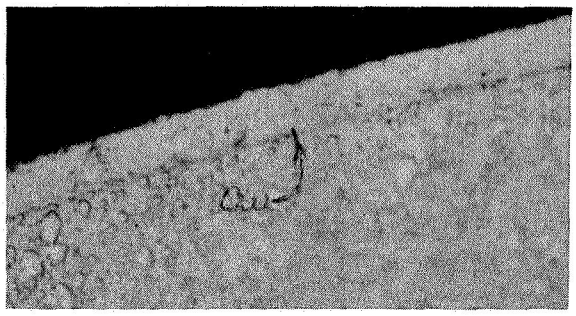

Figure 25 Specimen No. 8

Glass filled epoxy mount only

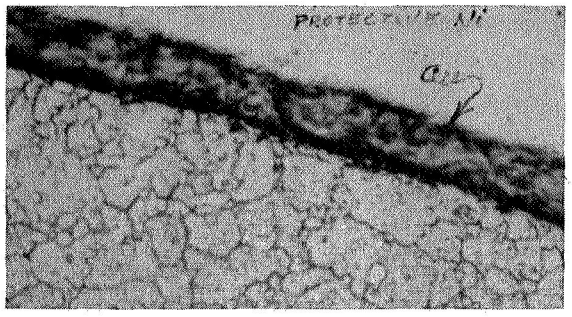

Figure 26 Specimen No.8-A

Protective Ni over the Au Plate

Figures 25 & 26 prepared with Unitron Metallograph.

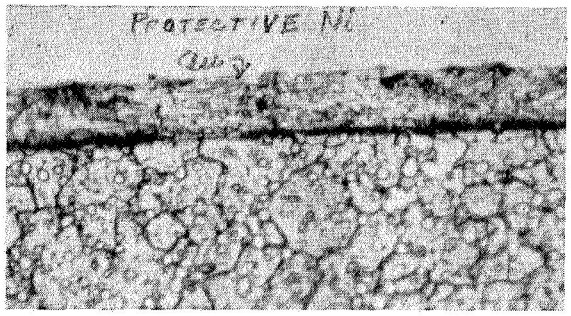

Figure 27 Specimen No. 8-A

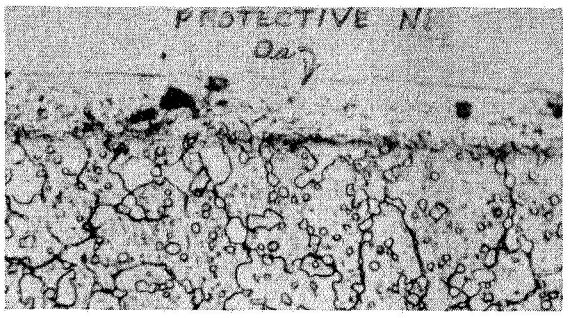

Figure 28 Specimen No. 8-A

Figures 27 & 28 prepared with B & L Research Metallograph.

Figures 26 & 27 show how Au plate was distorted and partially dragged out during polishing operations. Both photomicrographs are of the same general area of the same bearing ball, the difference being in the instrument used to obtain them.

Figure No. 28 shows an area of another ball where the Au plate is not so severely worked and virtually no drag-out occurred.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Plating Integrity
Discussion of Figures Nos. 25 - 28 Continued

Figures 25 and 28 point up, most clearly the tightness of the metallurgical bond between the Au plate and the substrate.

Substrate Material = 440-C Stainless Steel
Substrate Hardness = R/C 62-64
Substrate Etch = Picral – HCl
Au plating time = 60 minutes
Au plating thickness = Specimen #8 = 280×10^{-6} inches
Specimen #8-A = 262×10^{-6} inches

See * note on sheet No. 14 of this report for a discussion on the apparent discrepancies in the Au plate thickness between those balls with and without a protective nickel plating.

W. G. Grenier 7-24-63
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Au Plating Integrity
Photomicrographs at 1000 Diameters

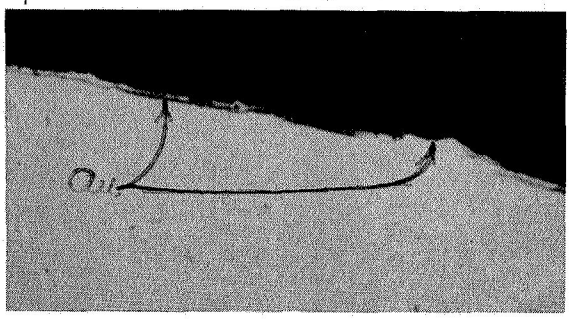

Figure 29 As Polished

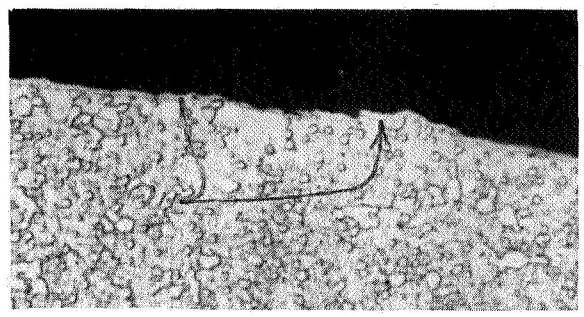

Figure 30 Etched

Specimen No. 9, as mounted in glass filled epoxy with no protective Ni plate over the Au plate.

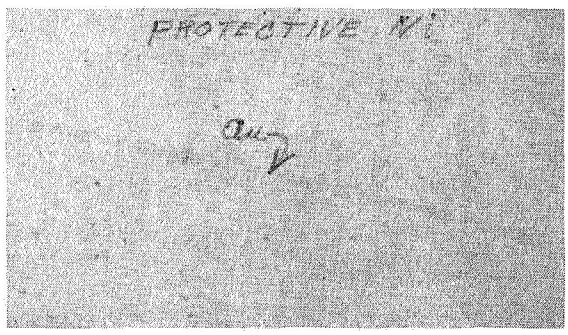

Figure 31 As Polished

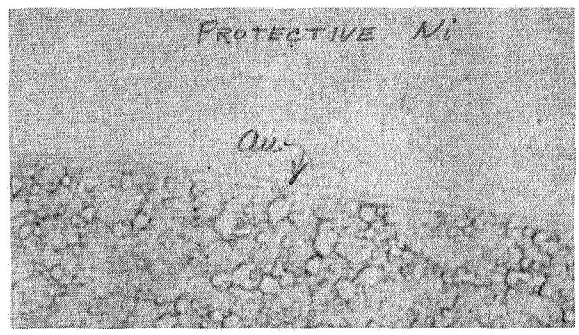

Figure 32 Etched

Specimen No. 9-A, with protective Ni plate over the Au.

Figures Nos. 29-32
Substrate Material = 440-C Stainless Steel
Substrate Hardness = R/C 61-63
Substrate Etch = Picral – HCl
Au plating time = 4 minutes
Au plating thickness = 21×10^{-6} inches

Above photomicrographs point up typical tight Au plate to substrate.

See Sheet No. 6 for discussion on apparent roughness of Au in Figs. 29 & 30.

W. G. Grenier 7-24-63
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings Study	673Y03-13	1200-36

DATA: Metallography of Au Plating Integrity
Photomicrographs at 1000 Diameters

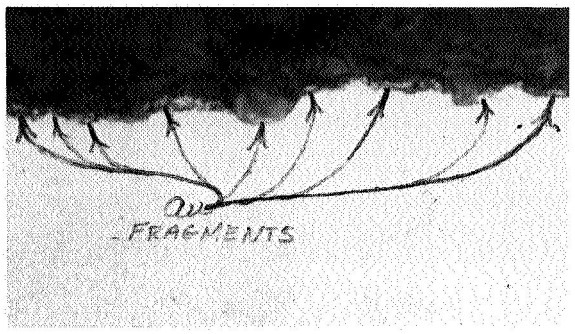

Figure 33 As Polished

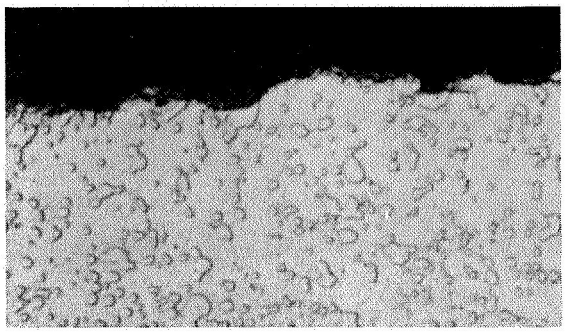

Figure 34 Etched

Specimen No. 10, in the as polished and the etched conditions. Areas shown are typical of this lot of Au plated balls as mounted in glass filled epoxy with no protective nickel plating over the Au. Note the apparent extreme roughness of the substrate surface and flaky appearance of the Au. Au plate definition was very difficult and it is felt thatthe thickness of plate as determined from this particular specimenccan be questioned.

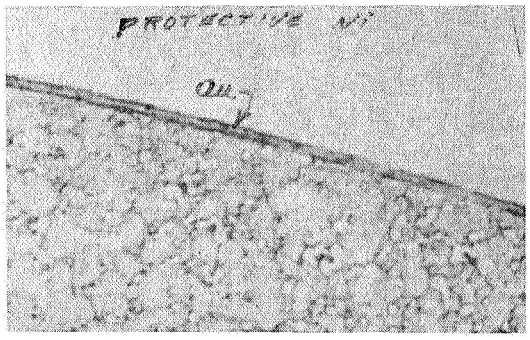

Figure 35 Specimen No. 10-A

Figures 33-35

Substrate Material = 440-C Stainless
Substrate Hardness = R/C - 64
Substrate Etch = Picral – HCl
Au Plating Time = 10 minutes
Au Plating Thickness = Spec. #10 = 43×10^{-6} ins.
Spec. #10-A = 61×10^{-6} ins.

Same lot of balls as above, but with protective Ni plate over Au. Light bond of Au to substrate is indicated.

See Sheet No. 6 for discussion on surface roughness.

W. G. Grenier 7-24-63
(Signature) (Date)

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-13

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Bearings	673Y03-14	M.R. 63-13 1200-36

CONCLUSIONS & Discussion:

The photomicrographs show that the plating is uniform, sound and has a good bond to the substrate. The photomicrographs show a difference in plating thickness and appearance when mounted with no overplating vs overplating. This difference, as stated, can be due to rounding of the edge, slight pull away of the gold or cold flow of the gold, and for possible reduction of thickness during surface preparation prior to overplating.

CONCLUSION:

1) The glass-epoxy mounting medium is not a suitable edge preservative for these type components and when possible, Nickel overplate should be used.

2) The gold plating put on by the Fabrication Division is sound, uniform and satisfactorily bonded.

3) The components in this report are 1/16 diameter 440C SS balls. Other bearing components have not been plated for examination.

C. E. Vest (Signature) 10-23-63 (Date)

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C.E. Vest	Belts-ville	125	Phase III Bearings	673Y03-13	1200-36

DATE IN	DATE COMPLETED	PERFORMED BY
7-29-63	10-8-63	W.G. Grenier & J. L. Wall

NAME OF TEST

Gold Plating: Thickness and Integrity Study

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

M.R. 63-14: 2 Au Plated Bearing sets labeled 124-D-70-14 & 124-LR-70-14

M.R. 63-15: 2 Au Plated Bearing sets labeled 124-C-D-6 & 124-C-LR-6

EQUIPMENT INVOLVED:

Micrometer calipers, bakelite ringforms, Hysol 2038 epoxy with Corning Borosilicate ground glass, oven, wet belt surfacer, Handimet hand polisher, Unitron metallurgical microscope equipped with Filar micrometer eyepiece and micrometric horizontal stage, B & L metallurgical microscope with dark field, 3 wheel slow speed polishing table equipped with an automet attachment for each wheel, diamond lapping compounds on silk polishing clothes, Gamal polishing Alumina on microcloth, metallurgical ultrasonic cleaner with trichlorethane and detergent solutions, various chemical reagents, slow speed hand polishing wheel, B & L Research Metallograph.

RESULTS:

1. Substrate Hardness Data given on Pg. 3
2. Gold Plate Thickness Data given on Pgs 4 - 7, incl.
3. Synopsis of Gold plate Thickness Data, given on Pgs. 8 & 9
4. Nomenclature of Assembly Components defined in Figs. 1-3, pg. 10
5. Metallographic results, see Figs. 4 - 21, incl., Pgs. 11 - 18, incl.

W. G. Grenier 10-11-63.
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Phase III Bearings	673Y03-13	1200-36

PROCEDURE: Au Plating, Thickness and Integrity Study

Four unused, complete, bearing assemblies were submitted by the Originator for plating thickness and integrity determinations. Each component of each assembly was plated with Gold. Two assemblies were plated and assembled by Donovan and two by Lea Ronal, and were so designated. It was desired to determine microstructural and plate thickness variations in the two platers results. Each assembly, submitted, consisted of: one inner race, one outer race, and one set of bearing balls.

Those procedures, outlined in the report on Metallurgical Requisition No. 63-3, dated 6-28-63, were followed in general. The exceptions to those procedures are as noted below:

1. Each disassembled assembly was submitted to Fabrication Division individually for protective Nickel Plating, thereby precluding any possibility of identification confusion.

2. The components were mounted in a glass filled epoxy medium, rather than lucite.

3. Each component was subjected to the second step etch for a very brief time period. This was used only as an aid in Au delineation, and proved most effective. Etching time was from 1/2 to 1-1/2 seconds.

4. Photomacrographs were prepared at 11, 20, and 45 diameters, to establish the typical cross section configuration of each component.

5. Photomicrographs were prepared at 1000 diameters only, employing the Bausch & Lomb Research Metallograph equipped with reflex back and Polaroid camera attachment. Due to the higher resolving power of this—new to the laboratory—instrument, greater detail is shown in the Au plate zone than in previous reports.

W. G. Grenier 10-9-63

(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Microhardness Tests of Component Substrates

Instrument: Kentron Microhardness Tester
Load: 500 gram Objective: 50 X Metal: 440-C Stainless

Component	Reading No.	Diag. Length Avg. F.U.	Hardness D.P.H.N.	Hardness Avg. R/C
124-D-70-14				
Inner Race	1	176	740	
	2	177	735	62
	3	178	730	
Outer Race	1	176	740	
	2	180	710	62
	3	179	720	
Bearing Balls	1	163	865	
	2	162	880	66
	3	163	865	
124-LR-70-14				
Inner Race	1	182	695	
	2	181	705	61
	3	177	735	
Outer Race	1	176	740	
	2	183	690	61
	3	182	695	
Bearing Balls	1	167	825	
	2	168	815	65
	3	169	805	

Component	Reading No.	Diag. Length Avg. F.U.	Hardness D.P.H.N.	Hardness Avg. R/C
124-C-D-6				
Inner Race	1	180	710	
	2	179	720	61
	3	179	720	
Outer Race	1	181	705	
	2	182	695	60
	3	179	720	
Bearing Balls	1	165	845	
	2	165	845	65
	3	168	815	
124-C-LR-6				
Inner Race	1	172	780	
	2	174	760	63
	3	175	755	
Outer Race	1	176	740	
	2	177	735	62
	3	178	730	
Bearing Balls	1	163	865	
	2	163	855	66
	3	164	865	

W. R. Grenier 10-9-63
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Gold Plate Thickness Determinations

Instrument: B & L Research Metallograph equipped with B & L Filar Micrometer Eyepiece, and 50 X (0.95 N.A.) Apo Objective lens. Optical combination calibrated with B & L Stage Micrometer. 1 F.U. = 2.628×10^{-6} inches.

Component	Location	Reading No.	Plate Thickness F.U.	Plate Thickness Ins.$\times 10^{-6}$
124-D-70-14				
Inner Race	Root of Raceway	1	35	92.1
		2	35	92.1
		3	30	78.9
		4	33	86.8
		Average	33.3	87.4
	Sides	1	31	81.5
		2	36	94.7
		3	31	81.5
		4	33	86.8
		Average	32.8	86.1
	Interior	1	163	428.7
		2	99	260.4
		3	39	102.6
		Average	100.3	263.9
Outer Race	Root of Raceway	1	20	52.5
		2	23	61.3
		3	23	61.3
		Average		58.3
124-D-70-14 Contd.				
Outer Race	Sides	1	12	31.6
		2	11	28.9
		3	21	55.2
		4	15	39.5
		Average		38.8
Bearing Balls	Ball-1	1	11	28.9
		2	9	23.7
		3	9	23.7
		4	10	26.3
		Average		25.8
	Ball-2	1	12	31.6
		2	10	26.3
		3	21	55.2
		Average		30.8
	Ball-3	1	37	97.3
		2	30	78.9
		3	36	94.7
		4	11	28.9
		Average		75.0

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Gold Plate Thickness Determinations, Contd.

Component	Location	Reading No.	Plate Thickness F.U.	Plate Thickness Ins.×10^{-6}
124-LR-70-14				
Inner Race	Root of Raceway	1	25	65.8
		2	22	57.9
		3	23	60.5
		4	26	68.4
		5	26	68.4
		6	29	76.3
		Average		66.3
	Interior	1	39	102.6
		2	38	99.9
		3	41	107.8
		4	47	123.6
		Average		108.6
Outer Race	Root of Raceway	1	37	97.3
		2	36	94.7
		3	40	105.2
		4	37	97.3
		Average		99.1
Bearing Balls	Ball-1	1	6	15.8
		2	15	39.5
		3	10	26.3
		4	11	28.9
		Average		27.6
124-LR-70-14				
Bearing Balls Contd.	Ball-2	1	18	47.3
		2	9	23.7
		3	12	31.6
		4	15	39.5
		Average		35.5
	Ball-3	1	10	26.3
		2	8	21.0
		3	8	21.0
		4	12	31.6
		Average		25.0
	Ball-4	1	15	39.5
		2	12	31.6
		3	42	110.5
		4	35	92.1
		Average		68.4

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Gold Plate Thickness Determinations, Contd.

Assembly: 124-C-D-6

Component	Location	Reading No.	Plate Thickness F.U.	Plate Thickness Ins.×10^{-6}
Inner Race	Root of Raceway	1	33	86.8
		2	24	63.1
		3	27	71.0
		4	30	78.9
		Average		75.0
	Interior	1	22	57.9
		2	10	26.3
		3	33	86.8
		Average		57.0
	Root of Raceway Other Side of Specimen	1	13	34.2
		2	15	39.5
		3	18	47.3
		4	17	44.7
		Average		41.4
Outer Race	Root of Raceway	1	15	39.5
		2	9	23.7
		3	10	26.3
		4	26	68.4
		5	14	36.8
		Average		38.9

Component	Location	Reading No.	Plate Thickness F.U.	Plate Thickness Ins.×10^{-6}
Bearing Balls	Ball-1	1	7	18.4
		2	11	28.9
		3	11	28.9
		4	9	23.7
		Average		25.0
	Ball-2	1	13	34.2
		2	11	28.9
		3	17	44.7
		4	24	63.1
		Average		42.7
	Ball-3	1	10	26.3
		2	8	21.0
		3	11	28.9
		4	10	26.3
		Average		25.6

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M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Gold Plate Thickness Determinations, Contd.

Assembly: 124-C-LR-6

Component	Location	Reading No.	Plate Thickness F.U.	Plate Thickness Ins.×10^{-6}
Inner Race	Root of Raceway	1	8	21.0
		2	7	18.4
		3	7	18.4
		4	9	23.7
		5	7	18.4
		Average		20.0
	Interior	1	16	42.1
		2	9	23.7
		3	15	39.5
		4	15	39.5
		5	3	34.2
		Average		35.8
Outer Race	Root of Raceway	1	7	18.4
		2	5	13.2
		3	9	23.7
		4	7	18.4
		5	10	26.3
		Average		20.0
Outer Race Contd.	Exterior	1	14	36.8
		2	17	44.7
		3	28	73.6
		4	23	60.5
		5	16	42.1
		Average		51.5
Bearing Balls	Ball-1	1	14	36.8
		2	15	39.5
		3	17	44.7
		4	20	52.6
		Average		43.4
	Ball-2	1	18	47.3
		2	17	44.7
		3	19	49.9
		Average		47.3
	Ball-3	1	21	55.2
		2	18	47.3
		3	19	49.9
		4	18	47.3
		Average		49.9

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Gold Plate Thickness, Synopsis

Assembly Identification	Component	Location	Au Plate Thickness (Inches $\times 10^{-6}$)		
			Numerical Average	Min.	Max.
124-D-70-14	Inner Race	Root of Raceway	87.4	78.9	92.1
		Sides	86.1	81.5	94.7
		Interior	100.3	102.6	428.7
	Outer Race	Root of Raceway	58.3	52.5	61.3
		Sides	38.8	28.9	55.2
	Bearing Balls	Ball-1	25.8	23.7	28.9
		Ball-2	30.8	26.3	55.2
		Ball-3	75.0	28.9	97.3
124-LR-70-14	Inner Race	Root of Raceway	66.3	57.9	76.3
	Inner Race	Interior	108.6	99.9	123.6
	Outer Race	Root of Raceway	99.1	94.7	105.2
	Bearing Balls	Ball-1	27.6	15.8	39.5
	Bearing Balls	Ball-2	35.5	23.7	47.3
	Bearing Balls	Ball-3	25.0	21.0	31.6
	Bearing Balls	Ball-4	68.4	31.6	110.5
124-C-D-6	Inner Race	Root of Raceway	58.2	34.2	86.8
	Inner Race	Interior	57.0	26.3	86.8
	Outer Race	Root of Raceway	38.9	23.7	68.4

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Gold Plate Thickness, Synopsis, Contd.

Assembly Identification	Component	Location	Au Plate Thickness (Inches $\times 10^{-6}$)		
			Numerical Average	Min.	Max.
124-C-D-6	Bearing Balls	Ball-1	25.0	18.4	28.9
		Ball-2	42.7	28.9	63.1
		Ball-3	25.6	21.0	28.9
124-C-LR-6	Inner Race	Root of Raceway	20.0	18.4	23.7
	Inner Race	Interior	35.8	23.7	42.1
	Outer Race	Root of Raceway	20.0	13.2	26.3
	Outer Race	Exterior	51.5	36.8	73.6
	Bearing Balls	Ball-1	43.4	36.8	52.6
	Bearing Balls	Ball-2	47.3	44.7	49.9
	Bearing Balls	Ball-3	49.9	47.3	55.2

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Photomacrographs: Nomenclature of Assembly

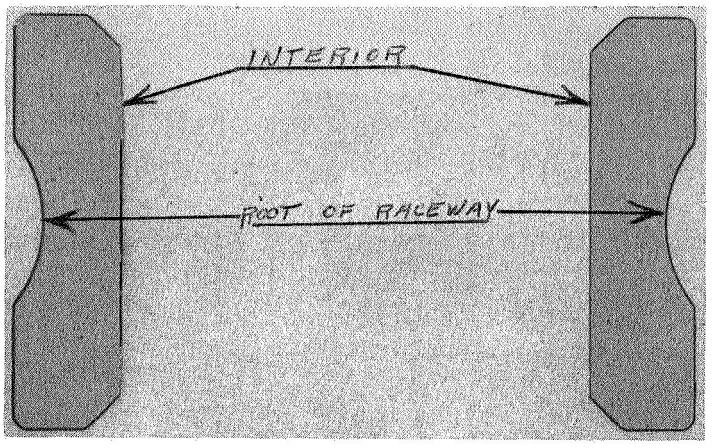

Fig. 1-Inner Race. 20 X.

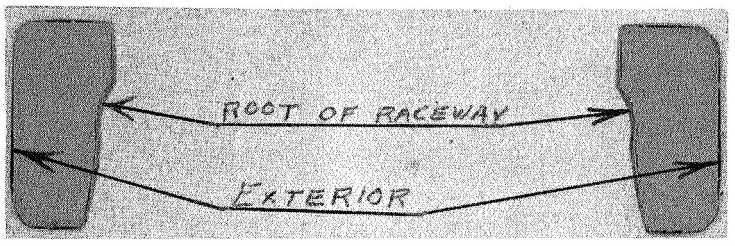

Fig. 2-Outer Race. 11 X.

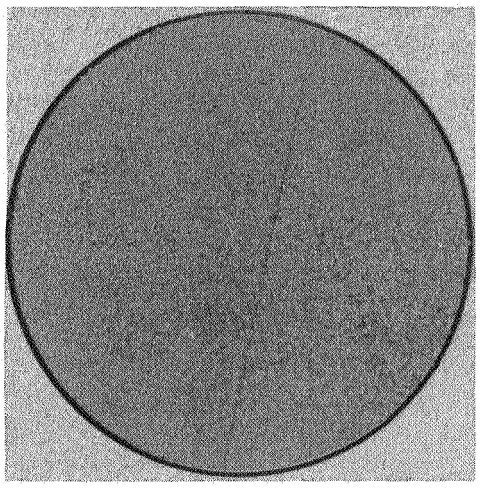

Fig. 3-Bearing Ball. 45 X.

Typical cross sectional configuration of assembly components. Etch: Picral-HCl followed by 1 sec. dip in 1/1 Acetic/HNO_3.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography Showing Au Plating Integrity.
Assembly 124-D-70-14

Substrate Mtl.: 440-C Stainless Steel
Magnification: 1000 diameters
Etch: 2 step, Picral-HCl + 1 sec. in 1/1 Acetic/HNO_3

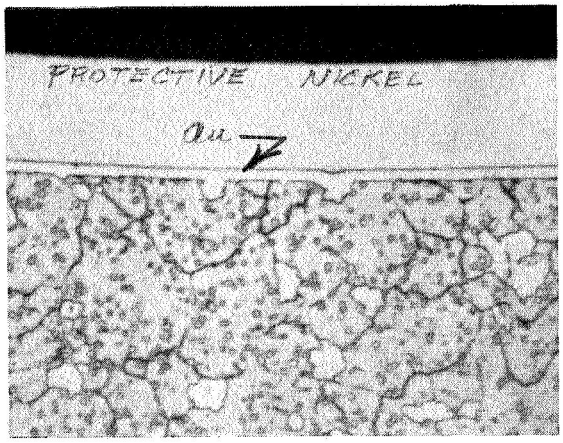

Fig. 4-Root of Raceway

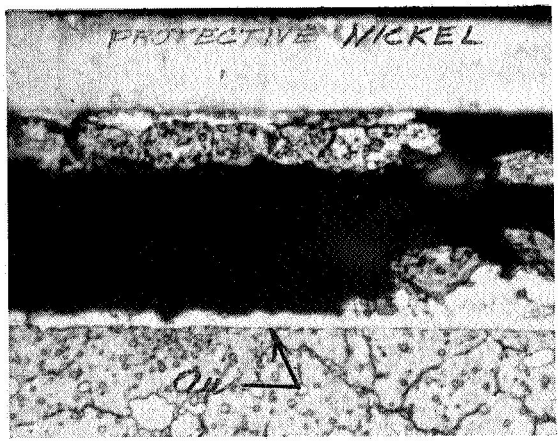

Fig. 5-Interior Surface

INNER RACE

Figures 4 and 5 point up tightness of the Au plating to the substrate, which was typical of the entire specimen.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography of Au Plate Integrity

Assembly: 124-D-70-14
Substrate Mtl.: 440-C Stainless Steel
Magnification: 1000 diameters
Etch: 2 steps

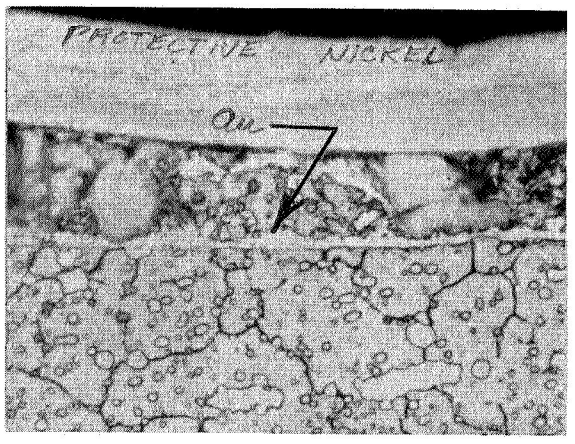

Fig. 6-Root of Raceway - Outer Race

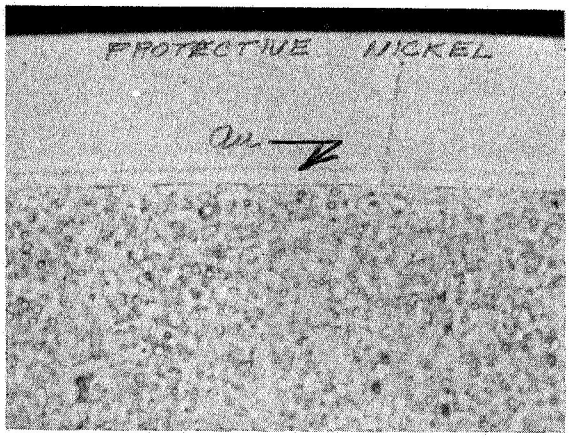

Fig. 7-Bearing Ball - Typical Surface

Figures 6 and 7 point up typical tightness of Au plating to the substrate.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography: Assembly 124-LR-70-14
Inner Race

Substrate Mtl.: 440-C Stainless Steel
Magnification: 1000 diameters
Etch: 2 steps

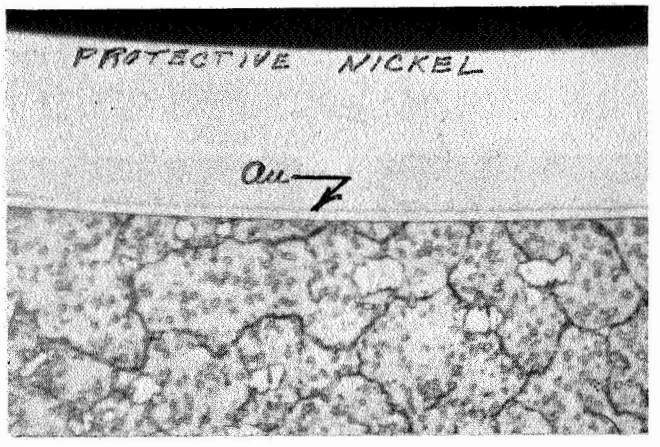

Fig. 8-Root of Raceway

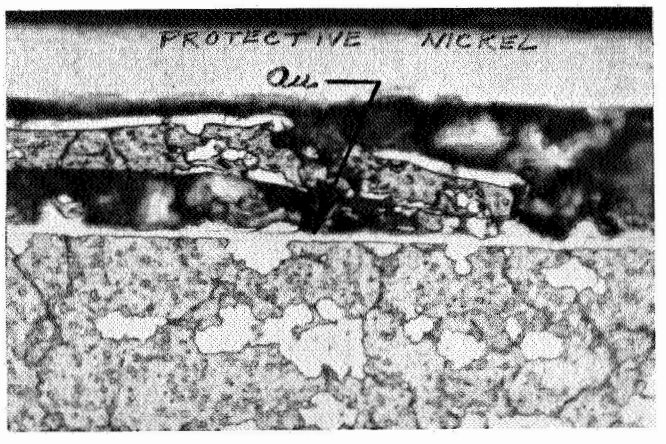

Fig. 9-Interior Surface

Figures 8 and 9 point up tightness of Au plate on Inner Race substrate.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography: Assembly 124-LR-70-14

Substrate Mtl.: 440-C Stainless Steel
Magnification: 1000 diameters
Etch: 2 steps

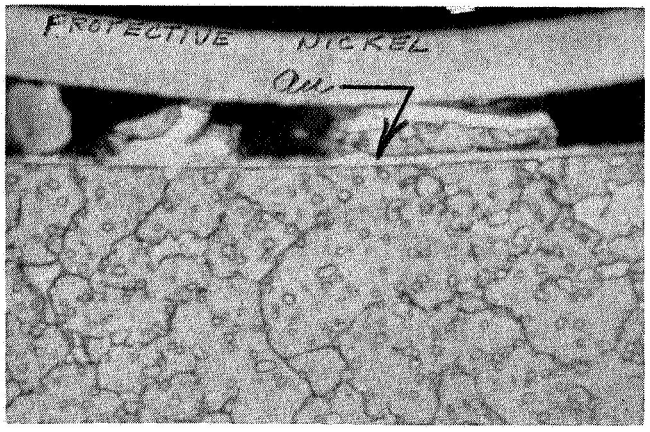

Fig. 10-Outer Race - Root of Raceway

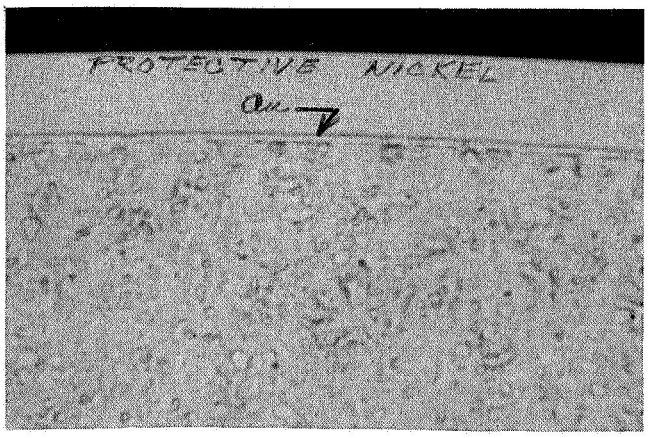

Fig. 11-Bearing Ball Surface

Figures 10 and 11 point up tightness of Au plate on components as indicated.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36
DATA: Metallography: Assembly 124-C-D-6			

Substrate Mtl.: 440-C Stainless Steel
Magnification: 1000 diameters
Etch: 2 steps

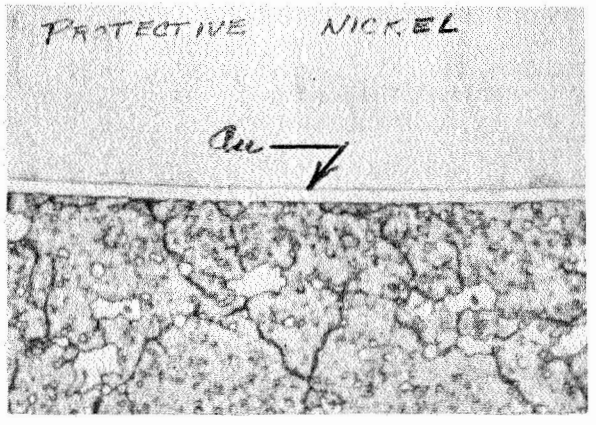

Fig. 12-Root of Raceway

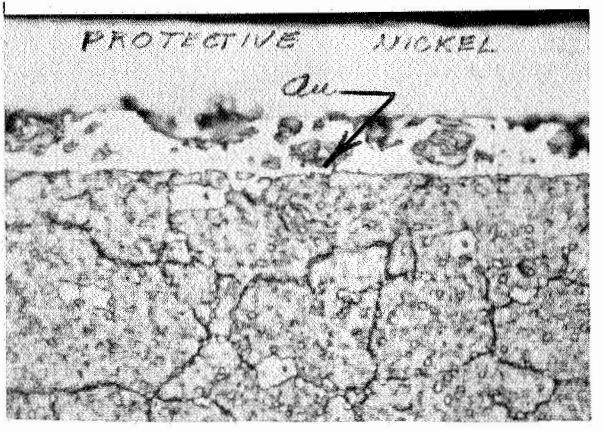

Fig. 13-Interior Surface

INNER RACE

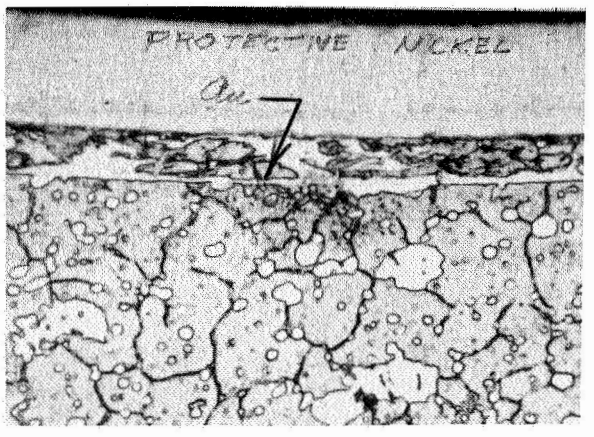

Fig. 14-Root of Raceway

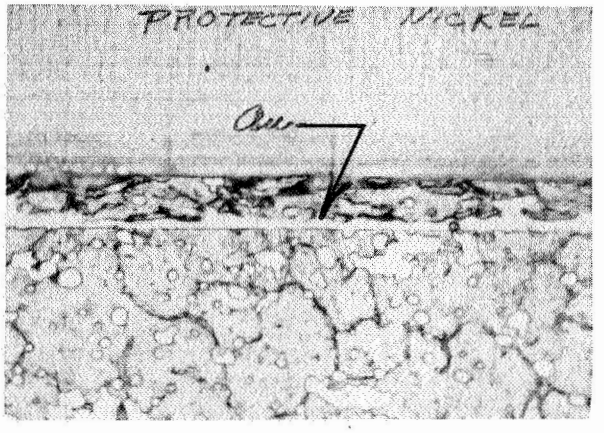

Fig. 15-Exterior Surface

OUTER RACE

Figures 12-15 inclusive, point up tightness of Au plate on substrate of designated components.

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SERVICE REPORT

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M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography: Assembly 124-C-D-6

Substrate Mtl.: 440-C Stainless Steel
Magnification: 1000 diameters
Etch: 2-step

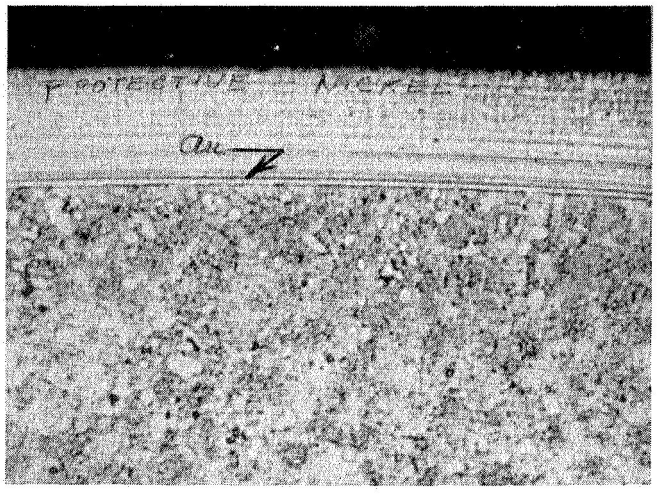

Fig. 16-Typical Bearing Ball

Figure 16 points up typical contiguous Au plating on Bearing Ball substrate.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography: Assembly 124-C-LR-6

Substrate Mtl.: 440-C Stainless Steel
Magnification: 1000 diameters
Etch: 2-step

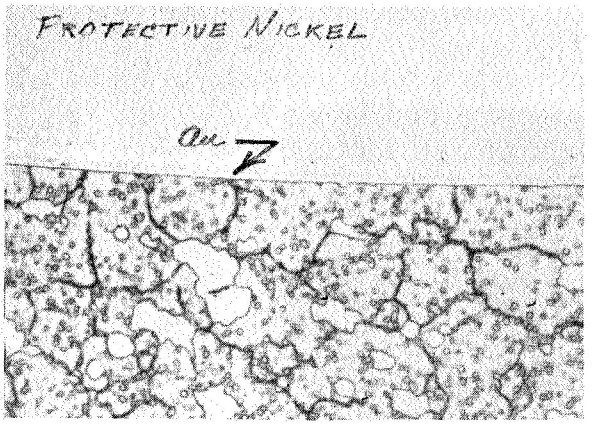

Fig. 17-Root of Raceway

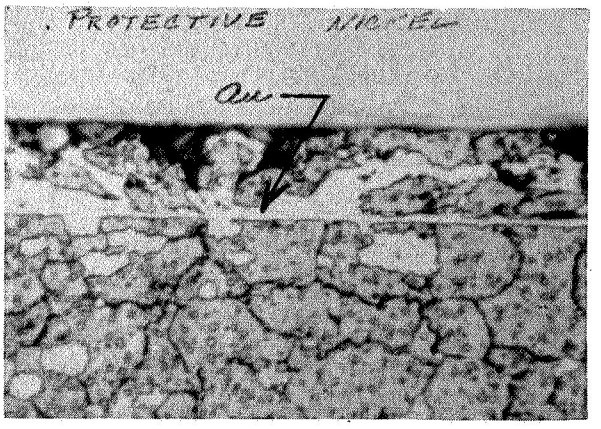

Fig. 18-Interior Surface

INNER RACE

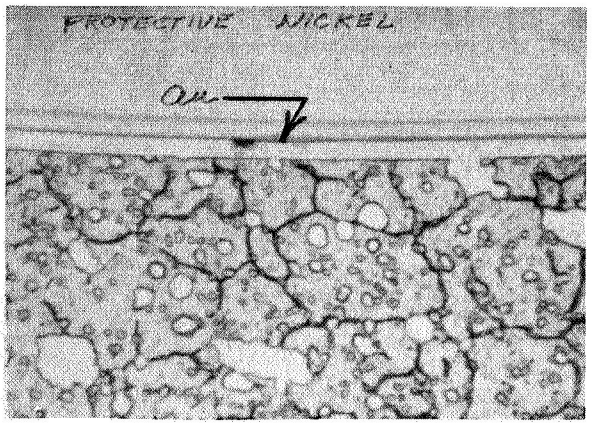

Fig. 19-Root of Raceway

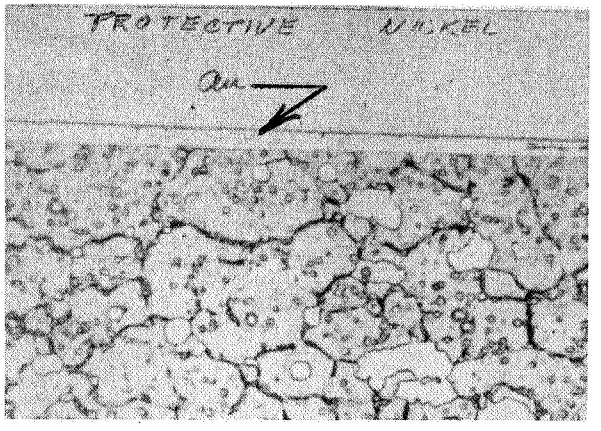

Fig. 20-Exterior Surface

OUTER RACE

Figures 17-20 inclusive, point up typical tightness of Au plate to substrate of indicated component.

W. G. Grenier 10-11-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

DATA: Metallography: Assembly 124-C-LR-6

Substrate Mtl.: 440-C Stainless Steel
Magnification: 1000 diameters
Etch: 2-step

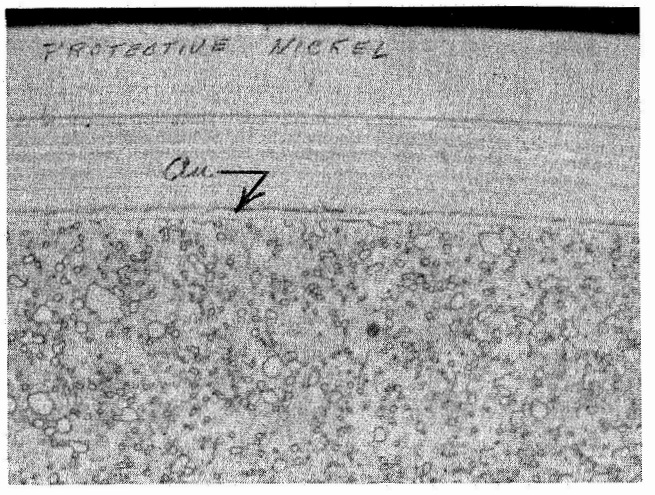

Fig. 21-Typical Bearing Ball

Figure 21 points up typical contiguous Au plating on Bearing Ball substrate.

W. G. Grenier 10-11-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-14 & 15

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	Phase III Bearings	673Y03-13	1200-36

CONCLUSIONS AND DISCUSSIONS:

The photomicrographs show that the gold is adherent on all specimens. The components numbered 124-D-70-14 & 124-LR-70-14 should have an average gold thickness of 70 micro inch. The components numbered 124-C-D-6 & 124-C-LR-6 should have an average of 30 micro inches of gold. An examination of the data, pages 9 & 10, shows that the 70 micro inch film thickness average for Donovan components from 91.3 to 44.0 and for the Lea Ronal components from 99 to 39. The film thickness for the 30 micro inch components for Donovan range from 57.6 to 31.3 and for Lea Ronal from 46.6 to 28.0. It was felt that the two plates could produce to within ± 25 micro inch on the average. The results are within this range within the accuracy of our measurement techniques. As the measurements indicate, the lifetime of these components could vary a great deal if lifetime is linear with film thickness. All specimens were prepared with a nickel overplate.

From the Discussion and reported data it is concluded that (1) the gold plate is adherent, (2) that the plating is not uniform in thickness from component to component, (3) that there is no significant difference in the quality of either plates, and (4) that the balls are more uniformly plated than the races.

Charles E. Vest 10-24-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C.E. Vest	Bltsvl.	125	MoS_2 in Situ	673Y03-14	1200-41

DATE IN	DATE COMPLETED	PERFORMED BY
5-20-63	9-11-63	W. G. Grenier & J. L. Wall

NAME OF TEST

Evaluation of effects of Mo S_2 in Situ process on various substrate materials.

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Two (2) specimens of each of the following materials; 1020 steel, 2024 Al, 6061 Al, 7075 Al, 316 stainless steel, 416 stainless steel and 440 stainless steel, were plated with a Mo O_3 complex. This was converted to the Mo S_2 in Situ by means of H_2 S gas, heat, and pressure. Each specimen was then examined, metallographically, for effects on the substrate microstructure which might be attributable to the process.

EQUIPMENT INVOLVED:

Misc. hand tools including slide rule and micrometer calipers, ultrasonic cleaner with various solvents, pickling solutions, hot plates, plating bath and apparatus, H_2S gas and conversion apparatus, aluminum foil, heat gun, glass filled epoxy, Bakelite ring forms, oven, rough wet belt surfacer with silicon carbide belts, Handiment hand polisher, slow speed polishing table equipped with Automet attachments, hand polishing wheels, various polishing cloths, 45μ- 15μ + 6μ diamond pastes, 600 grit Al oxide and silicon carbide powders. Gamal alumina, triple beam balance, various etchants and reagents, Rockwell hardness tester, B&L bench microscope, Macro Camera, Polaroid Model 110B Camera, B&L Research Metallograph, Polaroid type 47 film.

RESULTS:

There was no evidence of substrate contamination or attack, in any of the materials tested.

See Table I, sheet 23, for visual inspection results.
See sheet 24, for Metallograph Calibration data.
See sheets 25-37, incl. for Metallographic data, Figures 4 through 36, incl. This includes photomicrographs in the as polished and the etched conditions for each of the materials tested, all of which were discussed with the originator prior to inclusion in this report.

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PROCEDURE: General:

Fourteen (14) specimens, 2 each of 7 different types of alloys, were submitted to the Structural and Mechanical Applications Section by the Originator, for testing. The specimens were approximately 1" × 1/2" × from 1/8" — 1/4" in size. The materials were; 1020 steel, 2024 - T4 Al, 6061 - T6 Al, 7075 - T6 Al, 316 stainless steel, 416 stainless steel, and 440 stainless steel.

Each of these particular specimens were subjected to twice the normal electrodeposition of Mo $O_3 \cdot {}^{1}/_{3}\, M\, H_3 \cdot 6H_2O$. The exceptionally thick deposit of this Mo O_3 complex was converted to Mo S_2 by means of soaking the plated specimens in an H_2S atmosphere under heat and pressure for twice the normal conversion time. The severe conditions were desired to excentuate substrate contamination, if present. Each specimen was mounted, polished, etched, and examined, for any evidence of substrate contamination attributable to the conversion process. It should be noted that since no gross contamination was expected, a particularly diligent search was necessary.

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PROCEDURE: Mo S_2 in Situ, Process

The equipment shown here and on succeeding pages, is that used by the Structural and Mechanical Applications Section personnel sharing development procedures for the Mo S_2 in Situ program.

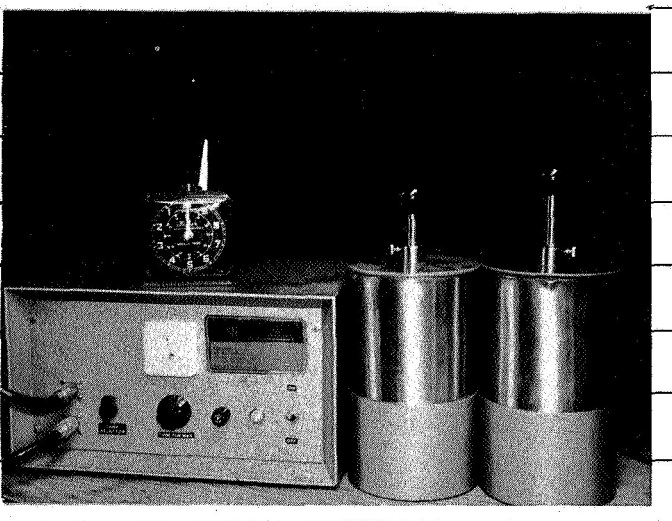

Figure 1

Figure 1 shows a photograph of the Metallurgical Ultrasonic Cleaner, with the Fisher interval timer, used in the precleaning of specimens to be coated with Mo S_2 in the Situ.

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C. E. Vest	Mo S_2 in Situ	673Y 03-14	1200-41

PROCEDURE: Mo S_2 in Situ, Process Contd.

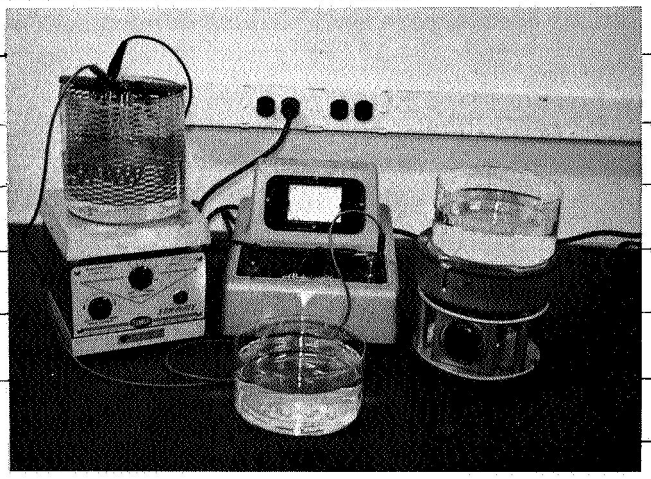

Fig. 2-Plating Apparatus

Photograph showing activation and plating equipment used for electrodepositon of the Mo O_3 complex on the various materials.

From left to right the equipment is; Tempco magnetic stirrer – hot plate with plating bath and electrodes in place for operation, Buehler Micromet etcher as power source with dish of distilled H_2O rinse in front, and hot plate with activation bath. Note that the plating anode is a Pt plated Ti mesh liner.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Mo S_2 in Situ, Process Contd.

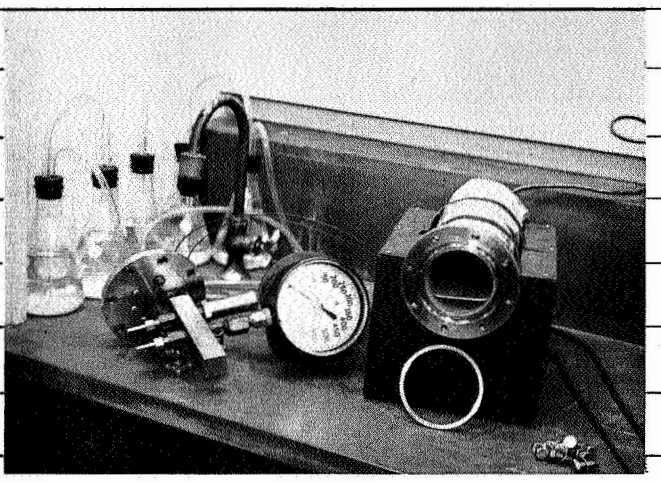

Fig. 3-Conversion Chamber

Photograph showing five (5) stage KOH filter system, front plate of conversion chamber with distribution manifold attached, safety relief valve, pressure guage, valve controlled hose bibs, and thermocouples, 25 aluminum 'O' ring seal, open conversion chamber, and outer wrapping which covers the heating tapes wound around the conversion chamber, The chamber is in the fume hood where it is operated.

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PROCEDURE: Mo S_2 in Situ, Process Contd.

Fig. 4-Conversion Equipment

Photograph of conversion chamber with support equipment, assembled and ready for operation.

From the left the equipment is; the KOH filter system, assembled conversion chamber, H_2S gas cylinders, and upper right-the variacs with associated ammeters for control of the heating tapes. The fume hood in the background, is the regular location for the conversion chamber and KOH filter.

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C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Mo S_2 in Situ, Process Contd.

Procedures for the complete Mo S_2 in Situ process, as it was adapted for these specimens, is presented here in outline form.

I Cleaning of Specimens

1. Immerse in Triton X-100 and water solution, and scrub ultrasonically for 3 minutes.
2. Rinse in warm flowing tap water.
3. Immerse in Ethyl alcohol and scrub ultrasonically for 2 minutes.
4. Immerse in Benzene and scrub as in 3 above.
5. Let soak in Benzene until ready for activation.

II Surface Activation of the Different Materials

(A) Mild (1020) steel

1. Immerse in 50% H Cl at room temperature for 2 minutes.
2. Rinse in free flowing tap water.
3. Plate immediately.

(B) All Aluminums

1. Immerse in 20% Na OH at 180° F for from 1/2 to 1 minute.
2. Rinse and plate as for mild steel.

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C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Mo S_2 in Situ, Process Contd.

II Surface Activation Contd.

(C) All Stainless Steels

1. Immerse in 20% H_2SO_4 at 180° F for 1 minute.
2. Rinse and plate as for mild steel.

III Plating of all Specimens

1. Prepare plating bath
   - 1.1. NH_4COOH - 109.2 gms
   - 1.2. $MoO \cdot H_2O$ - 25.2 gms.
   - 1.3. Distilled H_2O - 2000 ml.
   - 1.4. Heat, with constant stirring, to 80°C.
   - 1.5. Hold at temperature and stir until $MoO \cdot H_2O$ is completely in solution.
   - 1.6. Cool to room temperature for use.
2. Use Platinum plated Titanium, mesh anode.
3. Suspend specimens uniformily in plating bath.
4. Specimens are the Cathode.
5. Plate at 120 ma D.C. per square inch of surface area for 12 minutes.
6. Rinse in distilled water.
7. Air dry using the heat gun with switch on cold.
8. Wrap, like a sandwich, in aluminum foil.

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C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Mo S_2 in Situ, Process Contd.

III Plating of Specimens, Contd.

9. Place in Conversion Chamber on rack.

10. No more than 80 minutes may elapse between the plating of a specimen and its insertion into the conversion chamber.

IV Conversion of MoO_3 complex to Mo S_2 in Situ

1. Place wrapped specimens on the plate and insert into the conversion chamber.

2. Place 2s aluminum 'O' ring in its groove.

3. Secure the face plate containing the manifold.

4. Attach KOH filter tube to the inner hose bib. Be sure that that valve is closed.

5. Open valve at rear of conversion chamber.

6. Attach vacuum pump hose to forward hose bib and open that valve.

7. Evacuate chamber and close the forward valve.

8. Open the gas valves on the H_2S Cylinder, thus filling the chamber with H_2S gas.

9. Check for leaks.

10. When the pressure, inside the chamber, has stabilized at 255 + psi, shut all valves in back of the chamber including those on the gas cylinder.

11. Turn on Variacs in heating tape circuits.

12. Check ammeters in heating tape circuits to be certain that each tape is operative.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Mo S_2 in Situ, Process Contd.

IV Conversion (Contd.)

13. Set Variacs to read 95 volts each and hold until the manifold mounted pressure gauge reads 390 psi.
14. Reduce Variacs settings to 55 volts and adjust as necessary to maintain a chamber pressure of from 390 to 400 psi.
15. Hold pressure for 8 hours.
16. In this particular test run, it was necessary to maintain the Variacs at 75 volts in order to retain the desired chamber pressure. This means that the internal chamber temperature was between 250° C and 300° C.
17. After 8 hours at pressure has been maintained, open the inner hose bib valve and slowly bleed the gas from the chamber through the KOH filter system.
18. Open the valve at the rear of conversion chamber.
19. Connect a tank of inert gas to the forward hose bib, by means of flexible tubing.
20. Flush system with innert gas, filtering the residual H_2S through the KOH filter.
21. Close the forward hose bib valve and disconnect gas.
22. Open copper tubing joint at the H_2S tank and immediately hold, by hand, to tubing feeding innert gas.
23. Flush the system in this manner for from 1 to 2 minutes.
24. Remove the face plate, with manifold, from the conversion chamber.
25. Remove and observe the specimens.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Metallographic Examination

I Specimen History

Prior to coating with Mo S_2 in Situ, the following observations were made concerning the specific pieces of material used for these tests:

1. The 1020 steel, 6061 Al, 316 SS, and 416 SS specimens were taken from pieces of 1/8" thick sheet stock. They were sectioned and coated such that their mounted faces would be representative of their respective longitudinal cross sections.

2. The 2024 Al specimen was taken from the formerly gripped end of a 3/16" thick, flat tensile test specimen which had been tested to destruction. The mounted face is a transverse cross section.

3. The 7075 Al specimen was section from a 1/4" thick extruded angle stock. The mounted face is a transverse cross section.

4. The 440 Stainless Steel was obtained from a 1/4" thick block of previously used stock, whose orientation is unknown.

II Specimen Mounting Procedure

Following the plating and conversion process, each specimen was mounted in a glass and epoxy medium. The mix consisted of 3 parts, by weight, Hysol 2038 epoxy and 2 parts, by weight, of Corning Glass works Borosilicate Glass No. 7740, ground and screened to pass 90%

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Metallographic Examination, Contd.

II Specimen Mounting Procedure, Contd.

through U S standard mesh No. 325. Hysol hardener 3404 was added to the glass and base mix in the ratio of 1 part hardener to 16 parts mix, by weight. Care was taken to assure thorough mixing of the hardener with the glass and base mix.

Each coated specimen was placed inside a standard metallurgical bakelite ring form, located on a flat sheet of aluminum. Each speciman was oriented in conformity with sub title I, sheet 12 of this report. The epoxy preparation was then poured over and around each specimen, inside their respective ring forms, to the top of the form. Each ring form carried an appropriate temporary label to designate its specific contents. Subsequent to hardening, and curing, each mount was permanently labeled as to its individual content. Labeling was accomplished by means of a vibrator etcher on the back of the mount. From this point each complete mount is referred to as a specimen.

III Metallurgical Polishing

Each specimen was ground on the wet, silicon carbide, belt surfacer to remove about 0."030 of the specimen. This was followed by rough polishing on the Handimet hand polisher,

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
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PROCEDURE: Metallographic Examination, Contd.

III Polishing, Contd.

rotating each specimen 90° with each change to a finer grit polishing paper. It had to be kept in mind that the Mo S_2 layer on the exterior surface of each specimen would smear very readily. The primary interest was in the Mo S_2 to substrate interface and thesubstrate microstructure immediately adjacent to that interface. Therefore, care had to be taken, throughout the polishing sequence, to apply that pressure necessary to produce a cleanly cut surface with minimal flow, for each specimen. Simultaneously a flat, to the edge, surface had to be maintained.

In the final polishing stages, the slow speed Metallurgical lapping wheels were used exclusively in conjunction with the Automet polishing attachments. The polishing techniques varied with the three general classes of material. The specific techniques used for each class of substrate material is presented here in outline form:

(A) Mild Steel,

1. Polish with 600 grit aluminum Oxide on metcloth, with pressure of 40 lbs. for 4 minutes.
2. Clean-Ultrasonically in triton X-100 and water solution for 1 minute.
3. Rinse in warm water and dry with alcohol.
4. Polish with 6μdiamond on silk cloth, with a pressure of 40 lbs. for 3 minutes.

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C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Metallographic Examination, Contd.

III Polishing, Contd.

5. Clean with free flowing warm water, Triton X-100 swabbed, and alcohol.

6. Polish with Gamal on thoroughly dressed microcloth at a pressure of 30-40 lbs. for 2 1/2-3 minutes.

7. Prepare photomicrographs of as polished specimen.

(B) The Aluminums,

1. Polish with 600 grit Silicon carbide powder on silk cloth, at a pressure of 40 lbs. for 4 minutes. For the final 1/4 minute rinse wheel with free flowing tap water.

2. Clean by conventional means. Do not use ultrasonics, as this may loosen some of the Mo S_2 deposit.

3. Polish with 15μ diamond on silk cloth, at a pressure of 30 lb. for 3 minutes.

4. Clean as in A-5.

5. Polish with 6μ diamond on silk cloth, at a pressure of 30 lbs. for 2 minutes.

6. Clean as in A-5.

7. Polish with Gamal Alumina on thoroughly dressed Microcloth, at a pressure of 20-30 lbs. for 2 1/2-3 minutes.

8. Clean by conventional means, and prepare Photomicrographs of As Polished specimen.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Metallographic Examination, Contd.

III Polishing, Contd.

(C) The Stainless Steels,

1. Polish with 45μ diamond on silk cloth, at a pressure of 50 lbs. for 4 minutes.
2. Clean as in A-5
3. Etch in appropriate reagent, swab for 3-5 seconds.
4. Polish with 15μ diamond on silk cloth, at a pressure of 40 lbs. for 4 minutes.
5. Clean as in A-5.
6. Etch as in C-3 above.
7. Polish with 6μ diamond on silk cloth, at a pressure of 40 lbs. for 3 minutes.
8. Clean as in A-5.
9. Polish with Gamal Alumina on thoroughly dressed Microcloth, at a pressure of 30 lbs. for 3 minutes.
10. Clean by conventional means, and prepare Photomicrographs of specimen in As Polished condition.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E..Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Metallographic Examination, Contd.

IV Revealing the Microstructure,

Subsequent to the final polish, each specimen was prepared such that its true microstructure was revealed. This was accomplished through etching and repolishing techniques. It must be noted that the etching-polishing-etching techniques for any alloy depends on many variables, such as; heat treatment, residual stresses, specimen orientation, prior strains, and etc.. This means that the etching techniques must be constantly adjusted to the unique conditions of the specific specimen being studied. Therefore the techniques outlined herein, pertain only to these particular specimens with their respective specific histories. Therefore, the techniques employed in revealing the true microstructure for each substrate material is presented here in outline form.

(A) Mild (1020) Steel Substrate

1. Etch by immersion, in 4% Nital for 5 seconds.
2. Polish by hand on slow wheel, using Gamal on thoroughly dressed microcloth.
3. Etch as above for from 15-20 seconds.
4. Rinse and dry with Ethyl alcohol.
5. Prepared Photomicrographs.

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Metallographic Examination, Contd.

IV Revealing Microstructure, Contd.

(B) 2024 Aluminum

1. Etch in Kellers etch by immersion, observing carefully for first indication of color.
2. Rinse in warm free flowing water and dry with Ethyl alcohol.
3. Hand polish on slow wheel with Gamal on thoroughly dressed Microcloth.
4. Etch as above, allowing color to deepen slightly.
5. Rinse and repolish as above.
6. Etch as above and permit color to deepen considerably.
7. Rinse in warm, free flowing water.
8. Etch by immersion in 1% Na OH for from 5-7 seconds, enhancing contrast.
9. Rinse in water and dry with Ethyl alcohol.
10. Prepared Photomicrographs.

(C) 7075 Aluminum

1. Followed same schedule as for 2024 Aluminum excepting that step No. 8 was omitted.

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PROCEDURE: Metallographic Examination, Contd.

IV Revealing Microstructure, Contd.

(D) 6061 Aluminum

1. Etch by immersion and light swab technique in HF-H Cl etchant for 5 seconds.
2. Rinse and dry.
3. Hand polished on slow wheel with Gamal on thoroughly dressed Microcloth.
4. Etch as in D-1 for 10 seconds.
5. Rinsed in water and dried with alcohol.
6. Polish as in D-3.
7. Etched as in D-1 for from 15-2- seconds.
8. Rinsed as in D-5.
9. Prepared Photomicrographs.

(E) 316 Stainless Steel,

1. Etched with Marbles etch, by swab for 5 seconds, retaining specimen in the Automet specimen holder.
2. Rinsed in water and dried with alcohol.
3. Polish with Automet using Gamal on thoroughly dressed Microcloth and a pressure of 20 lbs. for 2 minutes.
4. Etched as in E-1 for 10 seconds.

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C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

PROCEDURE: Metallographic Examination, Contd.

IV Revealing Microstructure, Contd.

(E) 316 Stainless Steel, Contd.

5. Polished as in E-3 at 10 lbs. for 1 minute.

6. Etched in Marbles etch by immersion for 20 seconds.

7. Prepared Photomicrographs.

(F) 416 and 440 Stainless Steel Alloys,

The same general techniques as used in preparation of the 316 stainless steel were used. The exceptions to those procedures were as follows:

1. The etchant used was Picral-H Cl.

2. Final etching time for the 416 stainless steel alloy was 40 seconds.

3. Final etching time for the 440 stainless steel alloy was 15 seconds.

(G) Notes on techniques used,

1. It is to be noted that no specific times or pressures are given for, "by hand", repolishing operations between etching. In general, each succeeding polish should be of a shorter duration than its predecessor. A heavy hand pressure should never be used at this stage of specimen preparation. The actual lightness of touch will depend on the individual technician at the time.

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PROCEDURE: Metallographic Examination, Contd.

(G) Notes, Contd.

2. A, "thoroughly dressed Microcloth", is one from which nearly all the nap has been uniformally removed. This was accomplished by using a standard glass microscope slide, as a scraper. Dressing in this manner was necessary to alleviate nap-lash and edge relief.

(V) Photomicrography,

Photomicrographs were prepared, using the Bausch and Lomb Research Metallograph with a Polaroid Reflex camera back. The table of A.S.T.M. Standard Magnifications and Recommended Optical Combinations, supplied with the instrument, was used to obtain purported magnifications of 100, 250, and 500 diameters. After a significant number of photomicrographs had been prepared for this project, it was determined that the A.S.T.M table was not applicable when using the Polaroid Reflex Back. Therefore, a Bausch and Lomb stage micrometer, whose least division was 0.01 mm, was used to calibrate the metallograph for each of the optical combinations used. The true magnification for each photomicrograph is recorded with same in the data section of this report.

A new table of optical combinations was determined for future use, when employing the Polaroid Reflex Back on the Research Metallograph.

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PROCEDURE: Metallographic Examination, Contd.

V Photomicrography, Contd.

The magnification for which the accurate optical combinations have been established are; 100, 250, 500, and 1000 diameters. This table is to be found, and kept, with the instrument.

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DATA: Visual Inspection After Conversion Process

Table 1

Visual Inspection Results
Following
Mo S_2 in Situ Conversion

Material	Surface Appearance
1020 Steel	Grainy with some discoloration similar to rust.
2024 Al	Good, light gray
6061 Al	Good, dark
7075 Al	Good, dark
316 S.S.	Very flaky, flakes blow off leaving shiny metallic surface
416 S.S.	Grainy or pitted, shiny semi-smooth
440 S.S.	Good, uniform surface.

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DATA: Calibration of Metallograph with Polaroic Reflex Back.

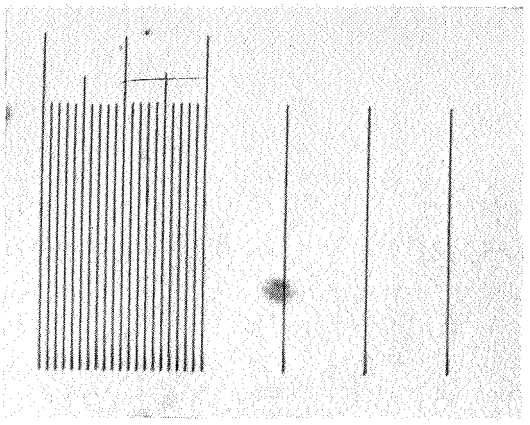

Fig. 1-120 X
Objective - 8 X (0.20 N.A.)
Eyepiece - 5 X Huygenian
Bellows Draw - 62.1 cm.

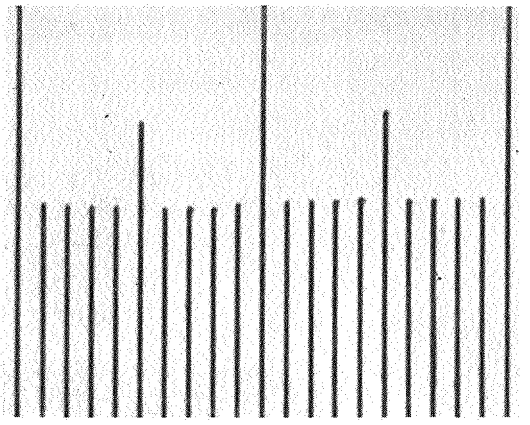

Fig. 2-360 X
Objective - 21 X (0.40 N.A.)
Eyepiece - 10 X Hyperplane
Bellows Draw - 30.9 cm.

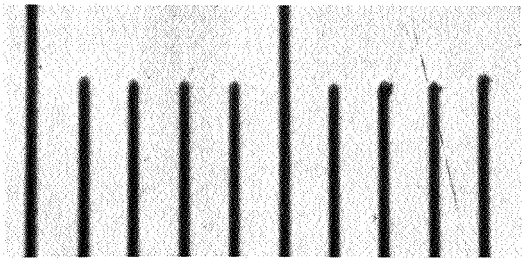

Fig. 3-740 X
Objective - 41 X (0.65 N.A.)
Eyepiece - 10 X Amplifier
Bellows Draw - 25.8 cm.

Figures 1-3 inc., are calibration photomicrograph using a B & L stage micrometer whose least division is 0.01 mm and whose major division is 0.10 mm.

W. G. Grenier 9-14-63
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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic, Mo S_2 in Situ on 1020 steel.

Fig. 4-360 X

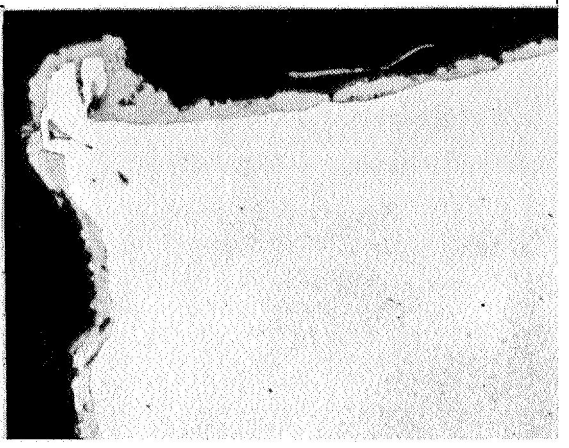

Fig. 5-360 X

Photomicrographs of Mo S_2 in Situ on 1020 steel in the As Polished condition pointing up the excellent contour following action of this type of lubricant.

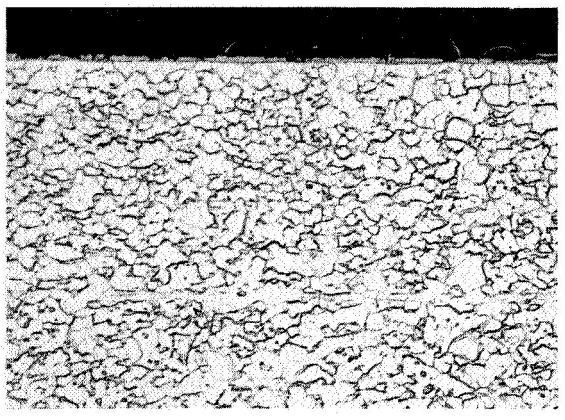

Fig. 6-120 X

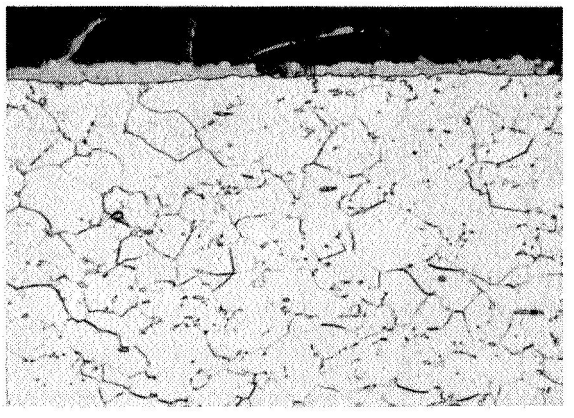

Fig. 7-360 X

Fig. 6 and 7: 4% Nital etch

Typical photomicrographs of 1020 steel substrate to Mo S_2 interface, indicating no evidence of substrate contamination.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic: Mo S_2 in Situ on 2024 - T4 Al

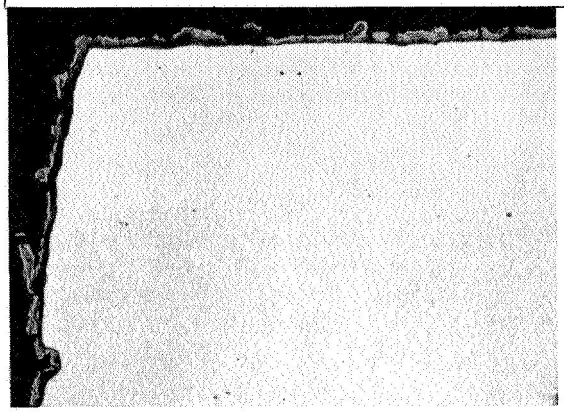

Fig. 8-120 X

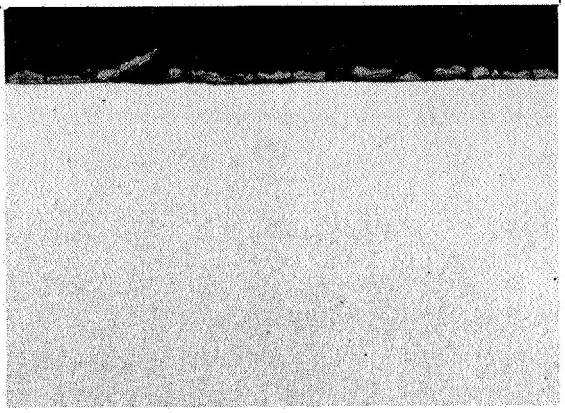

Fig. 9-120 X

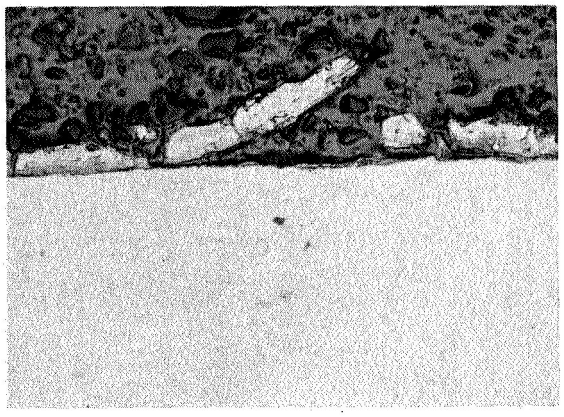

Fig. 10-360 X

Photomicrographs of the Mo S_2 in Situ on 2024 - T4 Aluminum in the As Polished condition.

These photomicrographs point up microscopic flaking as well as the ability of the coating to follow even minute deviations in the material surface.

Figure 10 shows thin film remaining under micro flake.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic: Mo S_2 in Situ on 2024 - T4 Al, Contd.

Fig. 11-120 X

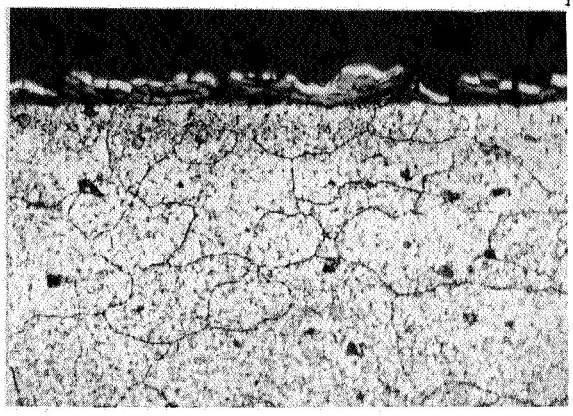

Fig. 12-360 X

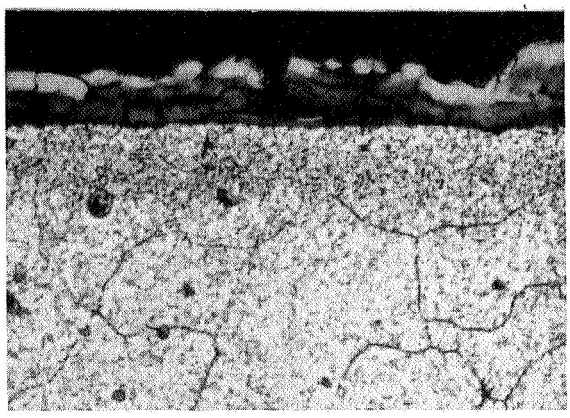

Fig. 13-740 X

Figures 11-13 inc., Etch: Kellers followed by 1% Na OH

The above photomicrographs point up the thin tight film of the Mo S_2 at the substrate interface, typical of this material.

No evidence of substrate contamination is apparent.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic: Mo S_2 in Situ on 6061-T6 Al

Fig. 14-120 X

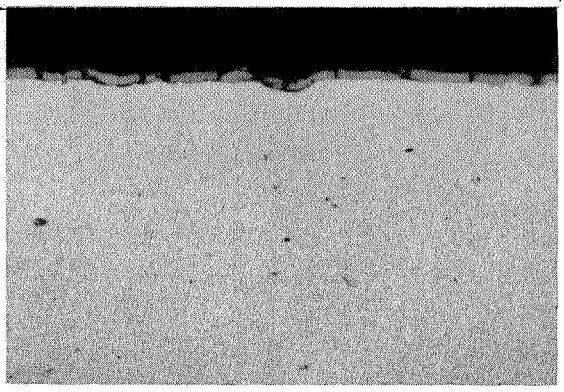

Fig. 15-360 X

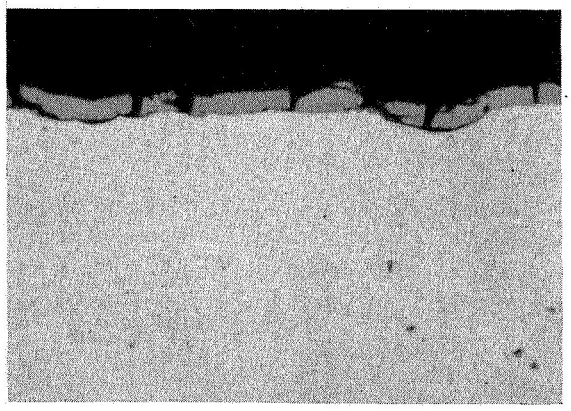

Fig. 16-740 X

Photomicrographs of the Mo S_2 in Situ on 6061-T6 Al substrate, in the As Polished condition.

These photomicrographs point up the tightness of the coating, and its characteristic ability to follow minute contour variations.

Note that in Table I, of the data, the coating appeared as a "Good, dark", coating while it is actually fragmented.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic: Mo S_2 in Situ on 6061-T6 Al, Contd.

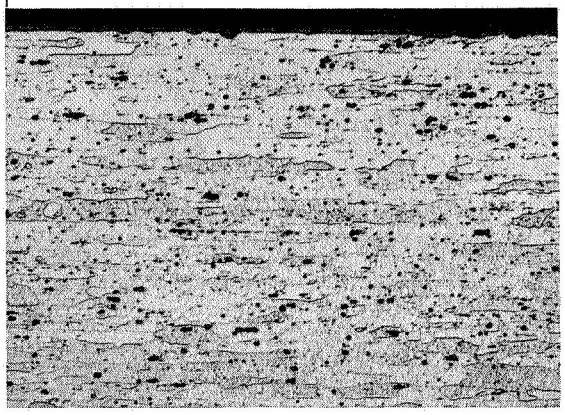

Fig. 17-120 X

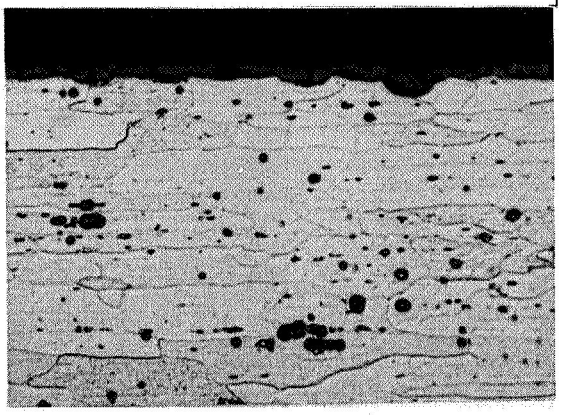

Fig. 18-360 X

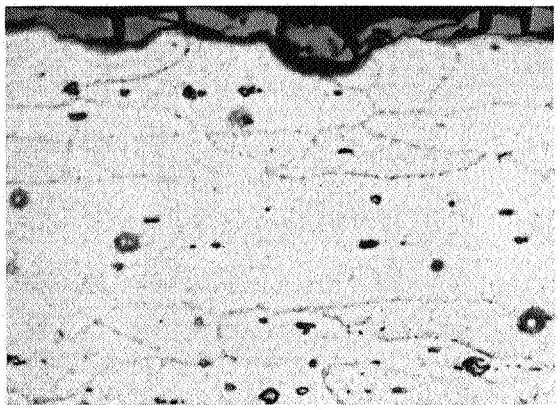

Fig. 19-740 X

Figures 17-19 inclusive, Etch: H Cl + H F

The above photomicrographs show the typical microstructure of the substrate 6061 Al adjacent to and at, the Mo S_2 to substrate interface. No evidence of substrate contamination is in evidence.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic: Mo S_2 in Situ on 7075-T6 Al

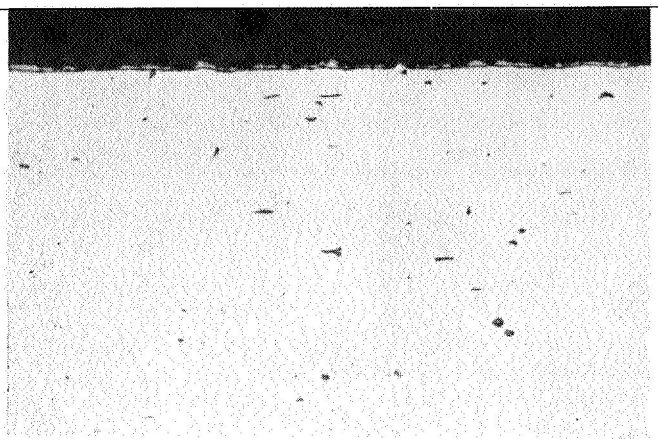

Fig. 20-360 X

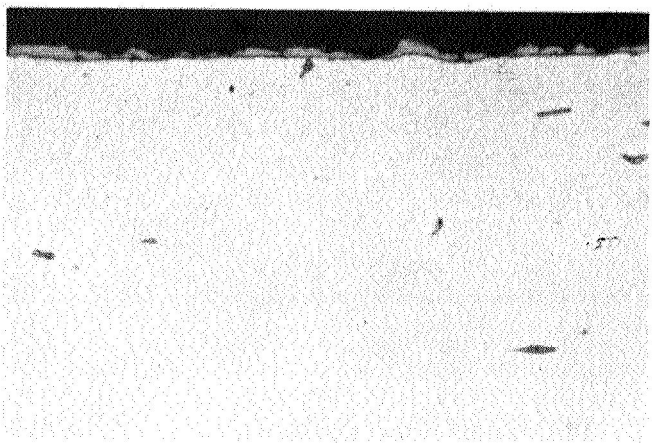

Fig. 21-740 X

Photomicrographs of the Mo S_2 in Situ on 7075-T-6 Aluminum substrate, in the As Polished condition.

Note the thinness of the coating as compared to the other materials substrates presented in the data.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic: Mo S_2 in Situ on 7075-T6 Al, Contd.

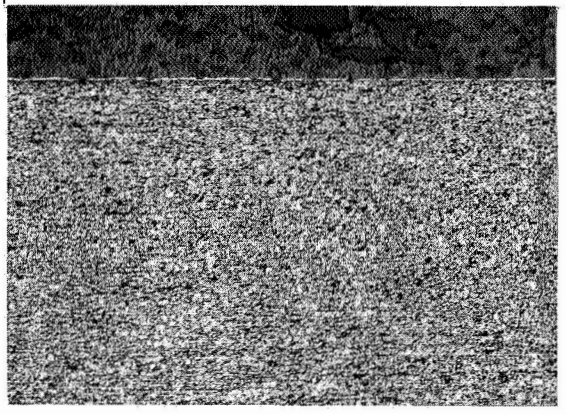

Fig. 22-120 X

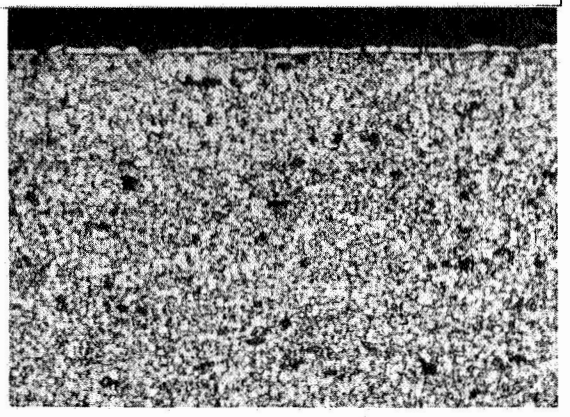

Fig. 23-360 X

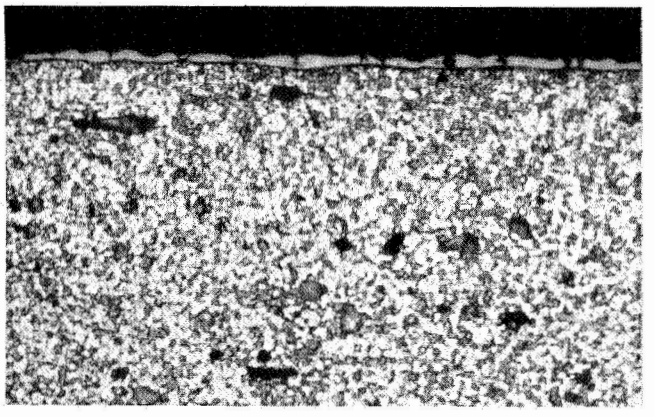

Fig. 24-740 X

Figures 22-24 inclusive, Etch: Kellers.

This substrate is representative of the transverse structure of the 7075-T6 Al extrusion, from which the experimental sample was taken. There is no evidence of substrate contamination.

The thin Mo S_2 appears uniform and tight.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41
DATA: Metallographic: Mo S_2 in Situ on 316 Stainless Steel.			

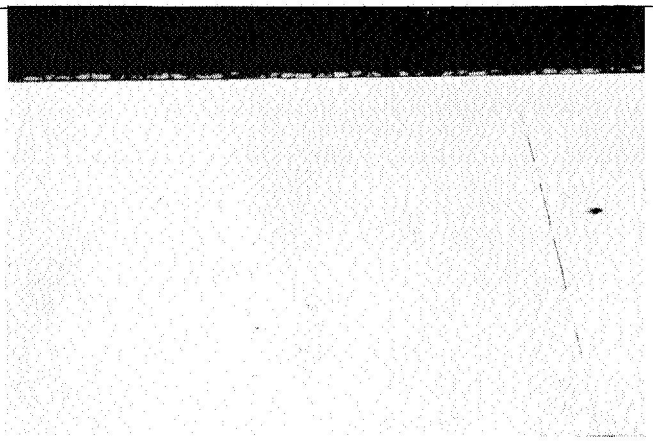

Fig. 25-120 X

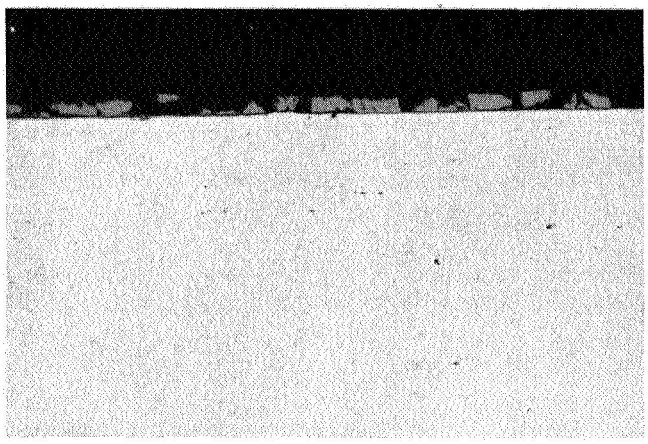

Fig. 26-360 X

Photomicrographs of the Mo S_2 in Situ on 316 type Stainless Steel Alloy, as polished.

Note the discontinuities in the Mo S_2 coating.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic: Mo S_2 in Situ on 316 Stainless Steel, Contd.

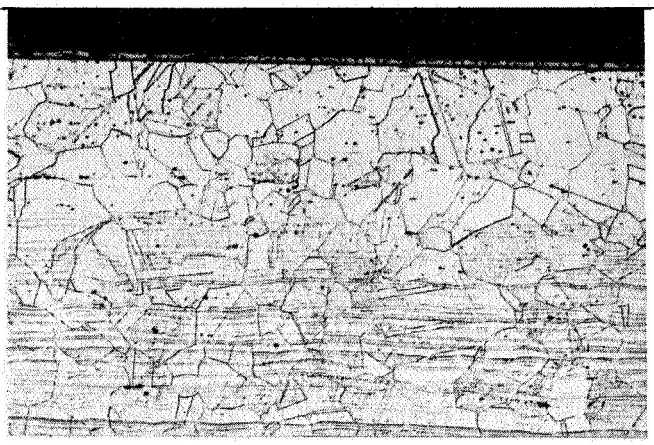

Fig. 27-120 X

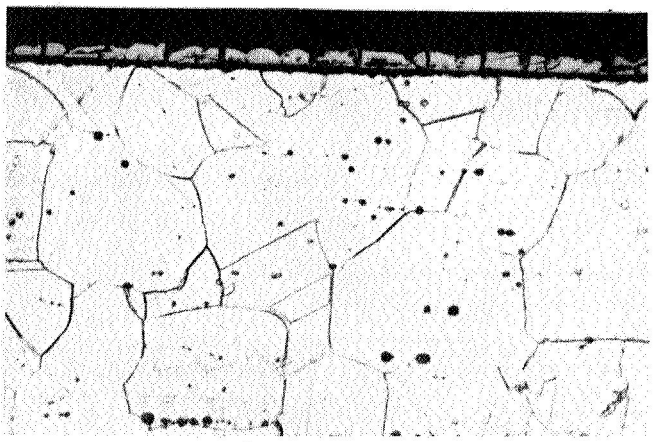

Fig. 28-360 X

Figures 27 and 28, Etch: Marbles.

Figure 27 shows banding of substrate, due to pre-experimental forging and rolling treatments.

No evidence of substrate contamination was found.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic: Mo S_2 in Situ on 416 Stainless Steel

Fig. 29-120 X

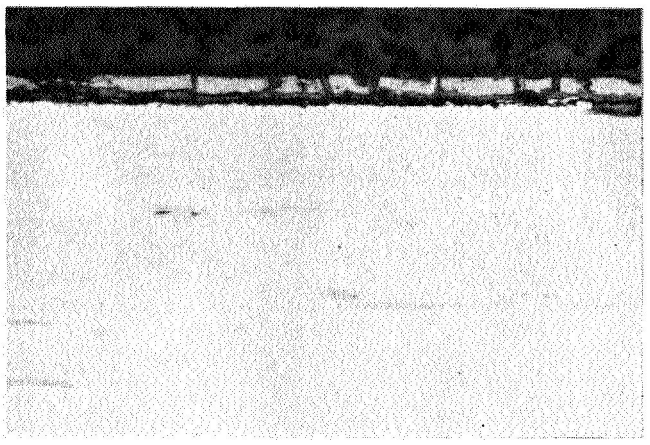

Fig. 30-360 X

Photomicrographs of the Mo S_2 in Situ on the 416 type stainless steel alloy, as polished.

Note the sulfide inclusions in the 416 S.S. substrate which account for its free machining characteristics.

Mo S_2 does not form tight bond.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic: Mo S_2 in Situ on 416 Stainless Steel, Contd.

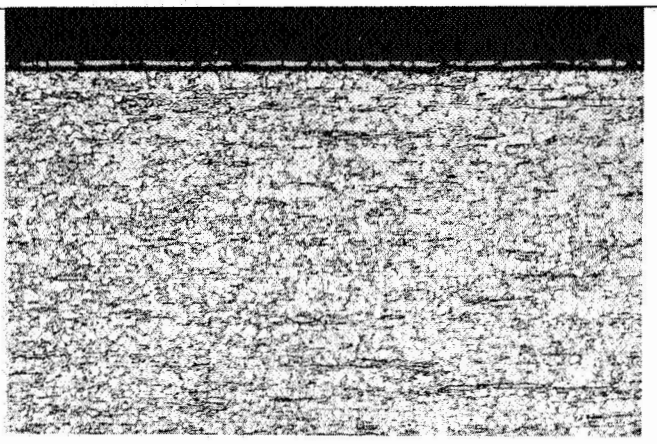

Fig. 31-120 X

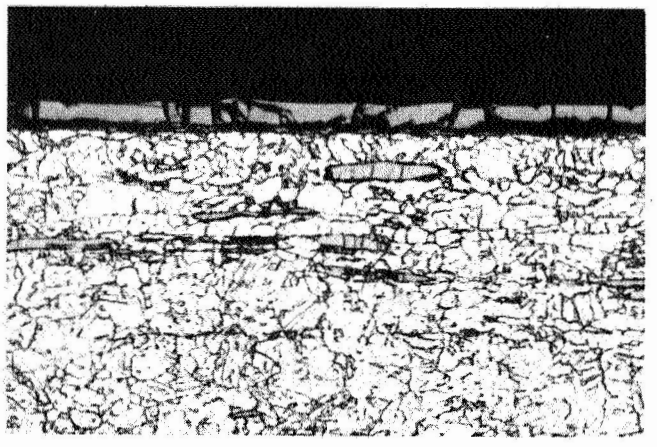

Fig. 32-360 X

Figures 31 and 32 Etch: Picral-H Cl.

These photomicrographs show the substrate microstructure, typical of 416 type stainless steel. Note that the sulfide inclusions appear similar to the Mo S_2.

No evidence of substrate contamination was found.

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic: Mo S_2 in Situ on 440 type stainless Steel

Fig. 33-120 X

Fig. 34-360 X

Photomicrographs of the Mo S_2 in Situ on the 440 type stainless steel alloy, as polished.

While the visual appearance of this material was considered to be clean and normal, see data Table 1, these photomicrographs show a very thin continuous layer of the Mo S_2 with the overlaying portion severely broken up and discontinuous.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

DATA: Metallographic : Mo S_2 in Situ on 440 type Stainless Steel, Contd.

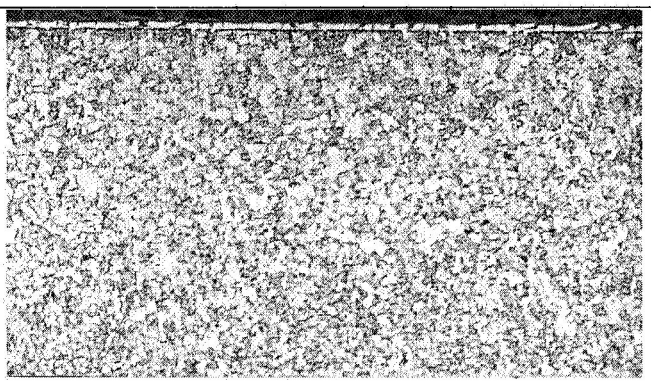

Fig. 35-120 X

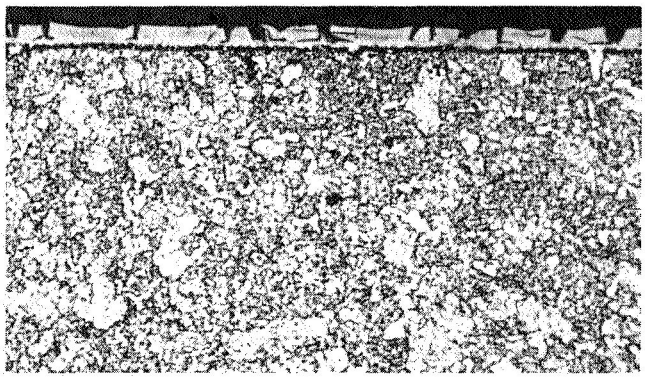

Fig. 36-360 X

Figures 35 and 36 Etch: Picral - H Cl.

Photomicrographs showing typical microstructure of the substrate 440 stainless steel adjacent to and at, the Mo S_2 to substrate interface. Note the thin, tight layer of conversion products in the interface.

No evidence of substrate contamination was found.

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SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 in Situ	673Y03-14	1200-41

Discussion of results:

As the conditions that the specimens or components are exposed to during the in Situ Mo S_2 process (concentrated H_2S gas under 400 psig pressure and 195°C for four hours) are not normal to spacecraft conditions and are severe to most earth applications, it was deemed advisable to determine the effect, if any, of these conditions upon a number of commonly used materials used in spacecraft construction and components.

In order to accelerate or accentuate any possible reaction with the substrate material, the normal processing conditions were not followed as we doubled the electrodepositions time and conversion time. It so happened that during conversion, a leak in the chamber seal occured which necessitated an increase in temperature to hold the pressure constant which in turn subjected the specimens to a higher temperature (estimated to be 250°C to 300°C).

The excessive electrodeposition time is known to produce a flaky, non-adherent coating as shown by the photographs in the report. As can be noted in the photographs, a thin adherent film is present under the flaky coating. An examination of the prepared specimen using the metallograph at high magnifications and an examination of the photomicrographs shown in the report, shows no indication or evidence of substrate attack by the in Situ processing conditions.

CONCLUSIONS:

No evidence of attack of the substrate materials tested (416SS, 440CSS, 316SS, 2024 Al, 6061 Al, 7075 Al and Mild steel) by the conditions of the in Situ Mo S_2 process was found.

C. E. Vest 9-17-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
F. Federline	6	S-204	ATD	673Y03-13	1200-10

DATE IN	DATE COMPLETED	PERFORMED BY
10-18-62	12-4-62	W. G. Grenier & C. E. Vest

NAME OF TEST

Metallurgical Examination

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Service: Metallurgical Examination for adhesion of SS to SS to determine if they are mechanical or intergranular diffused adhesions.

Articles: Type 303 stainless steel gears which failed after a short period of operation in vacuum. Gears were run in pairs either of which could be the driver.

EQUIPMENT INVOLVED:

Buehler, metallurgical specimen mounting press, cut-off wheel, standard metallurgical polishing apparatus, Fisher vibratory polisher, chrome Regia etchant, and Unitron Metallograph with Polaroid Camera attachment.

RESULTS:

At the request of the Originator, all data was submitted to Mr. C. E. Vest, for evaluation.

W. G. Grenier 12-4-62
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
F. Federline	ATD	673Y03-13	1200-10

PROCEDURE:

Photomacrographs at 10X were prepared of three (3) sets of gears. Photo file nos. 620157-620159. These show the gouges and metallic buildups to be studied.

Tooth sections were cut out of the various gears and mounted in lucite. These sections were ground and polished through the papers and wheels, and finally on the Fisher vibratory automatic polisher. Photomicrographs at 67X were prepared under file numbers 620255-620258 incl. showing side views of the same gouges and buildups mentioned above.

Each specimen was then etched in Chrome Regia to bring out the true microstructure and an additional set of photomicrographs was prepared at 67X, under file numbers 620259-620262 incl.

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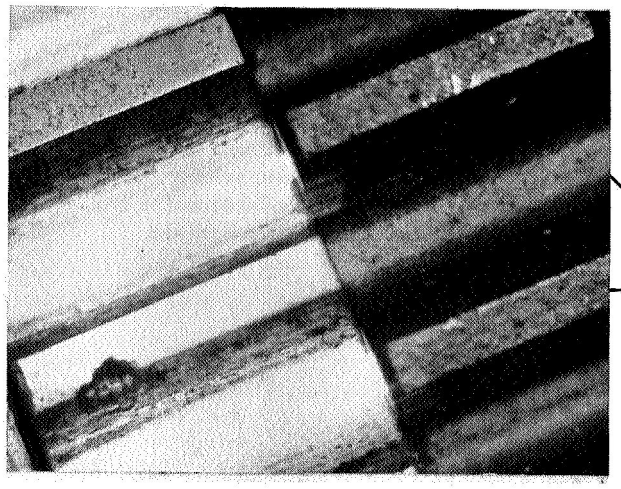
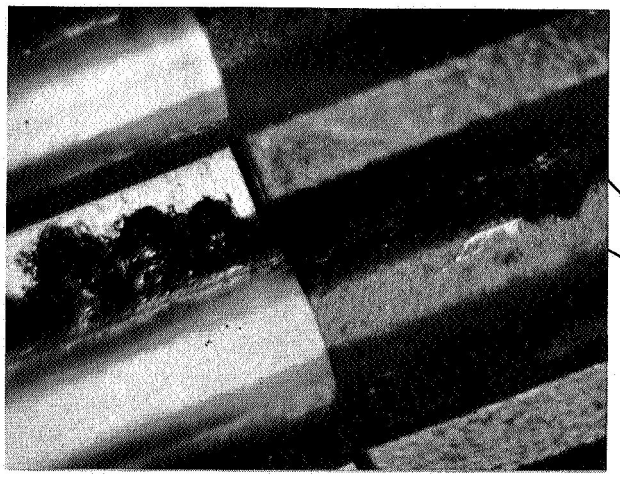
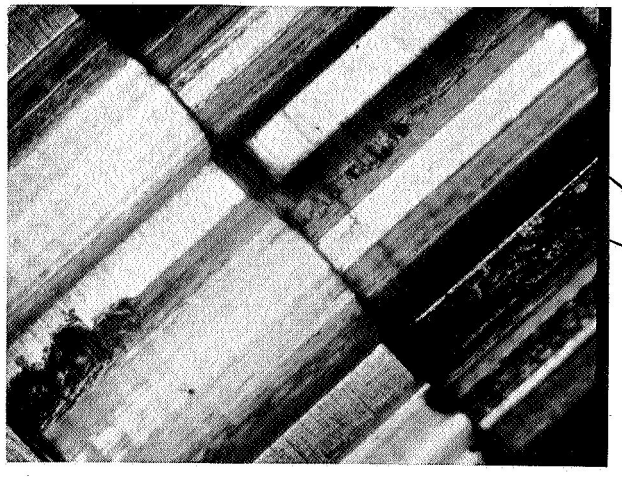


Photomicrograph #620157
Specimen 2A-2a – 10X
Electrofilm vs Cr plate
Buildup on Electrofilm
Score on Cr plate into SS



Photomacrograph #620158
Specimen 2A-2b – 10X
Electrofilm vs Cr plate
Buildup on Electrofilm
Scoring on Cr plate into SS



Photomacrograph #620159
Specimen 2A-2C – 10X
IBM-MoS_2 vs 303 SS
Scoring on IBM film
Scoring on SS tooth.
No buildup on either gear.

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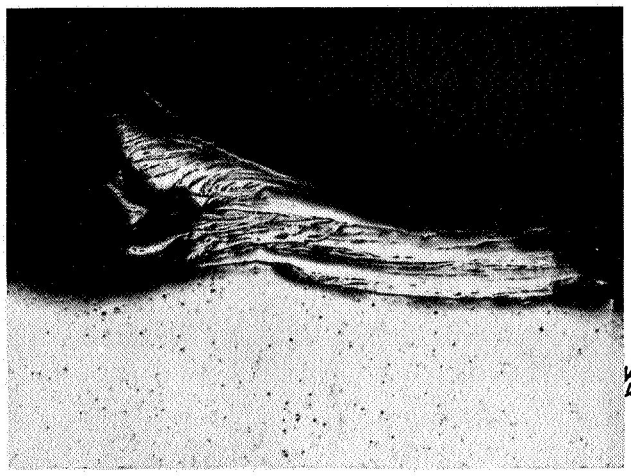
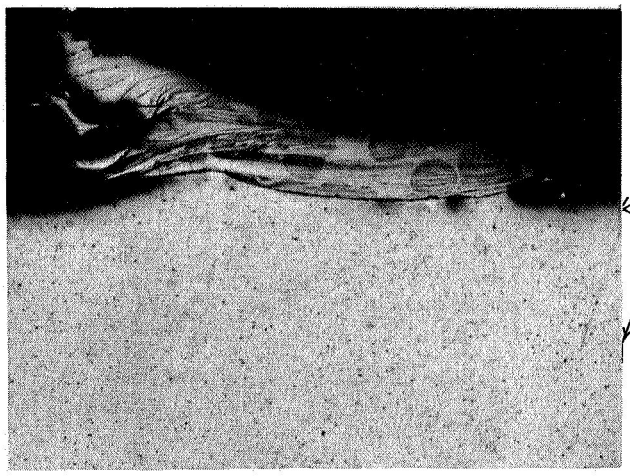
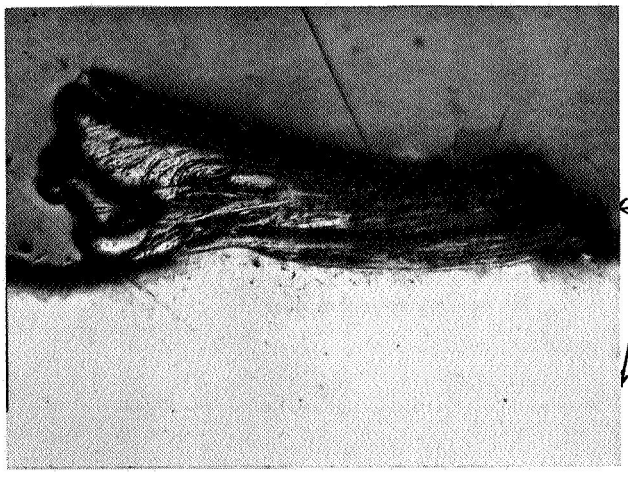
S.R. No. 1200-10







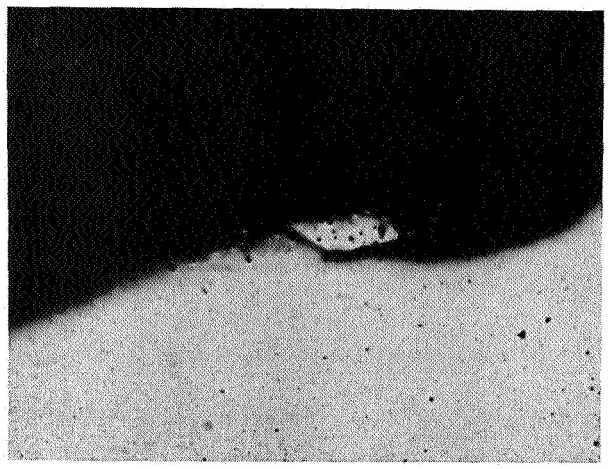
Photomacrographs #620261 67X
Three different etch and polish techniques showing build-up and different etching reaction between build-up and base material.

light etch

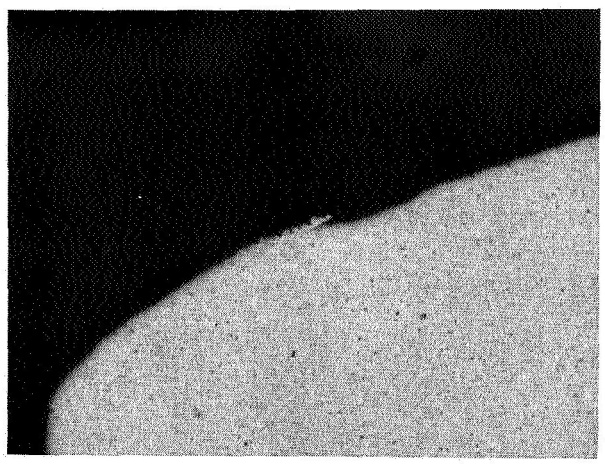
Buildup material shows layers of bond line.

Heavy etch

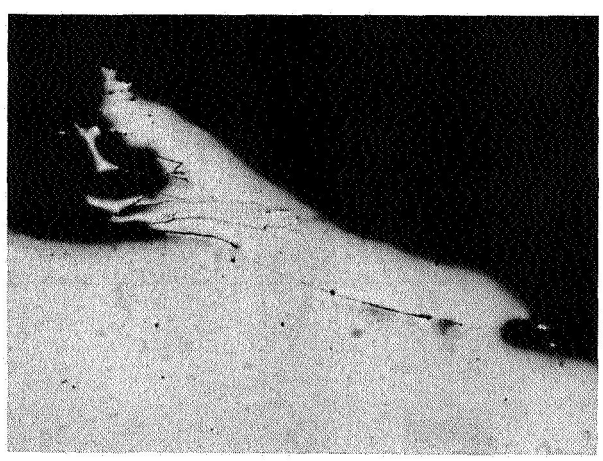
W. G. Grenier 12-4-62



Photomicrograph #620255 67X
Specimen 2A-2a as polished shows build-up on tooth and area where metal has been removed before build-up starts - Small gear



Photomicrograph #620256 67X
Specimen 2A-2a as polished
Small buildup and area where metal removed on large gear



Photomicrograph #620257 67X
Specimen 2A-2a
Build-up of material on Electro-film coated gear. Bond line shows lack of grain growth between base material and build-up. Also other lines of build-up are shown.

W. G. Grenier 12-4-62

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
F. Federline	ATD	673Y03-13	1200-10

CONCLUSIONS:

The determination of adhesion or mechanical adherence of the metal build-up to the gear tooth can not be decided from the limited amount of work to date. The photomicrographs taken show the scoring and build-up (10X & 67X) on the gear teeth. #620257 shows a large build-up and also in the unetched state, a definite bond line is evident. This means that the bond is not a metallurgical bond. Further investigation of the one specimen - heat treat at 1700°F and air cool - will recrystallize the severely cold worked build-up and upon additional polishing and etching, an examination of the bond line should show whether or not there is grain growth across the bond line Metallurgical bond. This should be completed by Dec. 10, '62. The influence of Electrofilm did not stop the build-up. The IBM MoS_2 layer did stop the build-up but this gear combination failed in less time than the Electrofilm gear combination.

C. E. Vest 12-6-62
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C. E. Vest	Beltsville	S46	ATD	634-Y03-13	1200-10

DATE IN	DATE COMPLETED	PERFORMED BY
12/7/62	12/14/62	W. G. Grenier

NAME OF TEST

Metallurgical Examination

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Specimens from large gear 2A-2b and small gear 2A-2C.

See enclosure one (1) for photographs.

EQUIPMENT INVOLVED:

Heat treating furnace, Specimen mounting press, granular lucite, Handimet surfacer, Fisher vibrating automatic polisher, Conventional polishing laps, Chemical hood, Chrome regia reagent, Unitron Metallograph with Polariod camera attachment, Kentron microhardness tester.

RESULTS:

See enclosure one (1) for Photomacrographs.

See enclosure two (2) for Metallographic results.

Following are the results from microhardness tests.

Spec No.	Avg. D.P.H.N.	Avg. Rockwell 'B' Conv.
2A-2b	153	81
2A-2C	155	81

W. G. Grenier 12-14-62
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	ATD	634-Y03-13	1200-10

PROCEDURE:

Specimens were first demounted, placed in furnace at 1650°F. Held at temperature for 15 minutes, then pushed to the rear of the furnace and allowed to cool with the furnace door opened about 1/4 of capacity.

When cool, the specimens were remounted in lucite and hand polished through the first wheel, using Fisher A-301 alumina as the polishing media. The final polish was achieved utilizing the Fisher vibratory automatic polisher to eliminate scratches. Photomicrographs were prepared in the as polished condition. The specimens were then etched lightly by immersion in chrome regia and additional photomicrographs prepared. Next the specimens were repolished by hand using the 1/4μ diamond paste on a slow wheel, and reetched by swabbing with chrome regia. This last procedure was repeated with chrome regia. This last procedure was repeated several times to bring out the complete microstructure of the material, and photomicrographs were prepared.

Following the metallographic study of the specimens, microhardness data was obtained on the Kentron microhardness tester.

W. G. Grenier 12-14-62
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	ATD	634-Y03-13	1200-10

PROCEDURE: DISCUSSION

The gears in this investigation were operated in vacuum as part of the "Gears for Vacuum Operation" program. They failed by jamming due to severe scoring and metal build-up on to a tooth of one gear. The lifetimes of 2A-2b and 2A-2c are 137 hours and 1.5 hours respectively. The vacuum obtained during operation was in the 10^{-8} Tor range. The 2A-2b set of gears are 303SS, one coated with chromium plating and one with Electrofilm (MoS_2 with sodium silicate binder). The 2A-2c set of gears are 303SS, one bare and one with IBM-MoS_2 coating. The gear used in this investigation is one of the 2A-2b set that was coated with MoS_2. Electrofilm. Photomacrographs #1 and #3 of enclosure #1 shows the scoring and metal build up experienced. Photomacrograph #1 and #2 shows the metal build up that is discussed from this point on.

After heat treating to remove the forged structure and to recrystalize the material, the specimen was examined with the metallograph under high magnification. It is evident that there is an intermittant metallurgical bond (welding) between the adhered metal and the base metal. (See Enclosures #2 photomicrographs 5, 9, and 10).

W. G. Grenier 12-14-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	ATD	634-Y03-13	1200-10

DISCUSSION: (Cont'd)

The method of failure is postulated as follows:

The high impact of the gears meshing causes a failure of the chromium and MoS_2 films (a hard coating should be backed up with a hard substrate, if not, the impact blows will cause the hard film to crack and spall). The hard, sharp chromium edges removed the MoS_2 from the mating gear teeth eventually removing sufficient MoS_2 and oxide to allow bare metal to contact. This caused "cold welding" of a small piece of material which with time scored, gouged, exposed more bare metal for "cold welding" with subsequent build-up layers of metal causing gear failure. The resulting build-up or lump of metal is shown in the photomicrographs in Enclosure #2.

Microhardness measurements were made on the adhered metal and base metal. The hardness of the adhered metal ranged from 302 to 191 D.P.H.N. with an average of 242 while the base metal ranged from 159 to 146 with an average of 153 DPHN. This difference in hardness is due to the smaller grain size, fine percipitate, and areas of high chromium in the adhered metal which is expected.

As these gears were a part of the "Gears for Vacuum Operation" program and they failed by removal of the protective film – MoS_2, chromium, and oxides – and subsequent scoring and adhesion ("cold welding") of the gears, it is recommended that future tests be performed on hardened gears coated with the various test films.

W. G. Grenier 12-14-62
(Signature) *(Date)*

Report on S.R. No. 1200-10
Gear Assembly 2A-2b, Photomacrographs

12-18-62

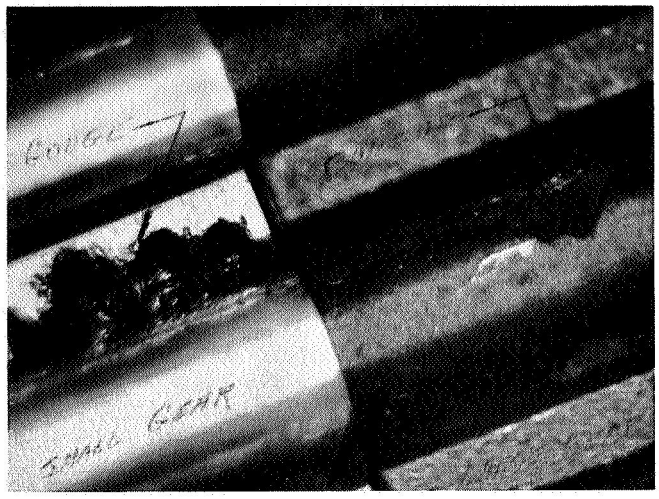


Figure 1 10X

Gear teeth of assembly 2A-2b

Section under study was taken from large gear across area labeled Buildup.

Figure 2 6.7X

Specimen from 2A-2b

Adhered segment, labeled "Buildup" in Figure 1, located on edge at X.

Report on S.R. No. 1200-10 12-18-62
Gear assembly 2A-2c, Photomacrograph

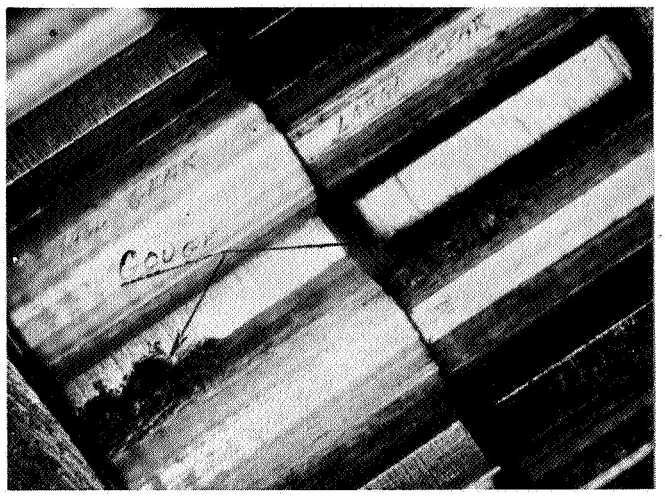


Figure 3 10X

Gear teeth of assembly 2A-2c

Section under study was taken from Small Gear.

Figure 4 6.7X

Specimen from 2A-2c Small gear

Gouge, shown in Figure 1, located on edge at X.

Report on S.R. No. 1200-10

Photomicrographs of segment adhered to large tooth of gear assembly 2A-2b. Shows Adhered segment and basic Gear material.

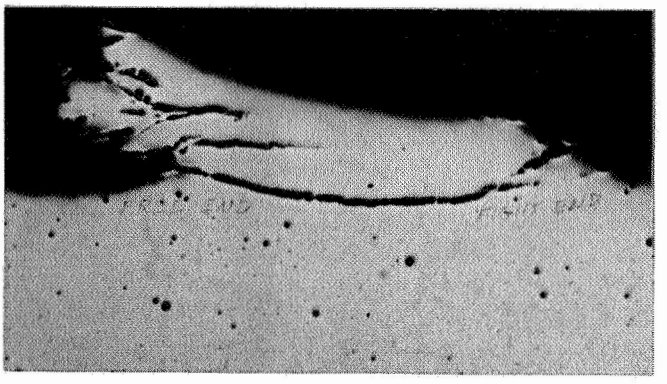


Figure 1 As Polished 67X

(Fisher Vibratory Auto. Polisher)

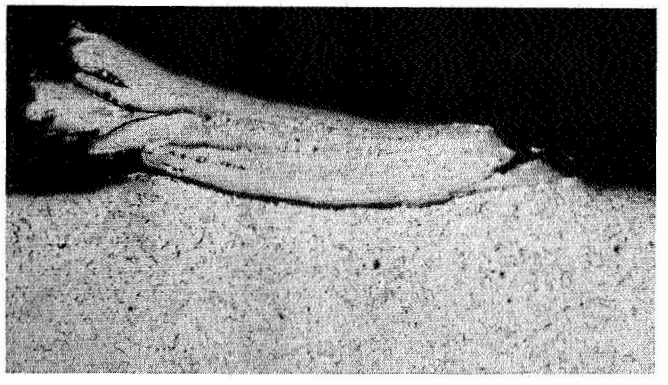


Figure 2 Light Etch 67X

(Chrome Regia by Immersion)

Figure 3 Full Etch 67X

Repolished using 1/4μ diamond paste and hand lap etch in Chrome Regia by swabbing

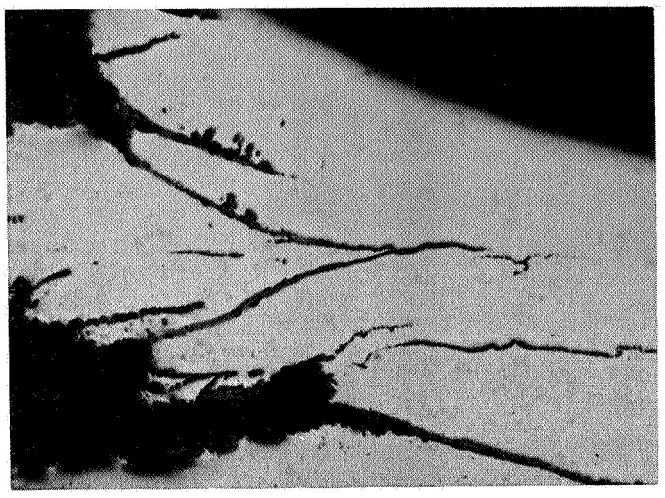


Figure 4 Free End 200X

As Polished

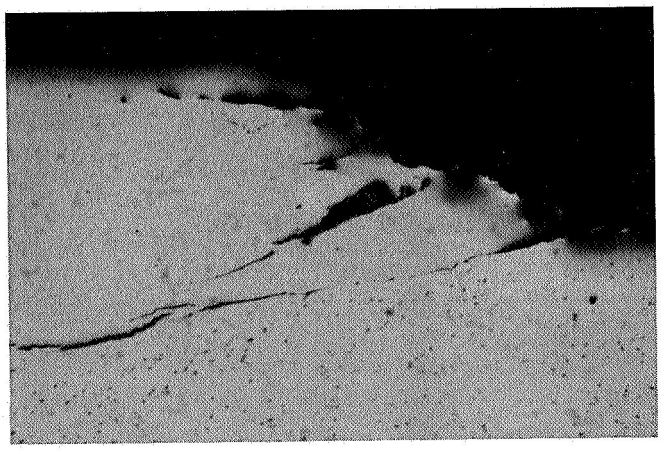


Figure 5 Tight End 200X

As Polished

Photomicrographs of 2A-2b large gear, adhered segment, free end and tight end as per Figure 1, Encl. 2.

2000 magnifications photomicrographs of segment adhered to tooth of large gear, gear assembly 2A-2b.

Repolished and etched by swabbing with Chrome Regia.

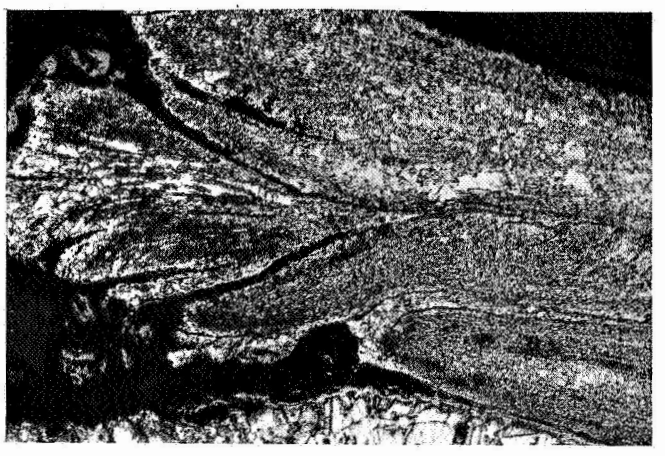


Figure 6–Free end of adhered segment

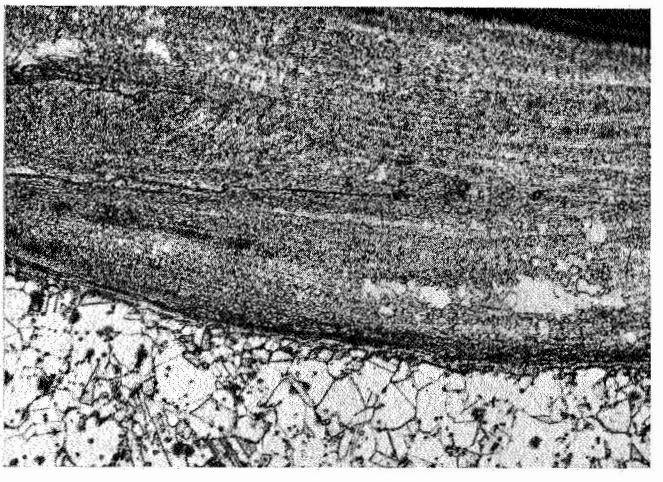


Figure 7–Mid section of adhered segment

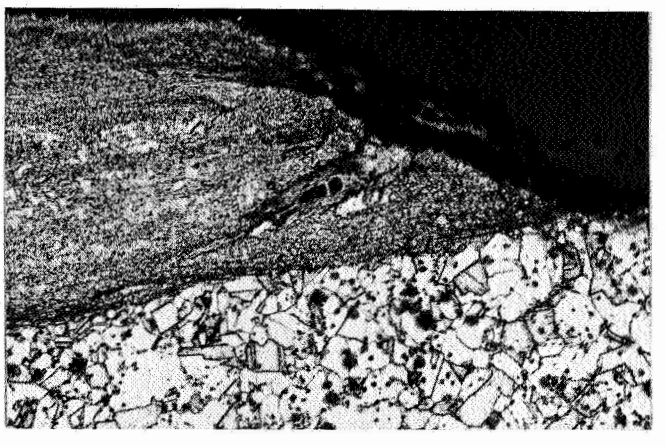


Figure 8–Tight end of adhered segment

Photomicrographs showing typical microstructure of interface region, near the tight end of the adhered segment, as brought out by swabbing with chrome Regia etchant.

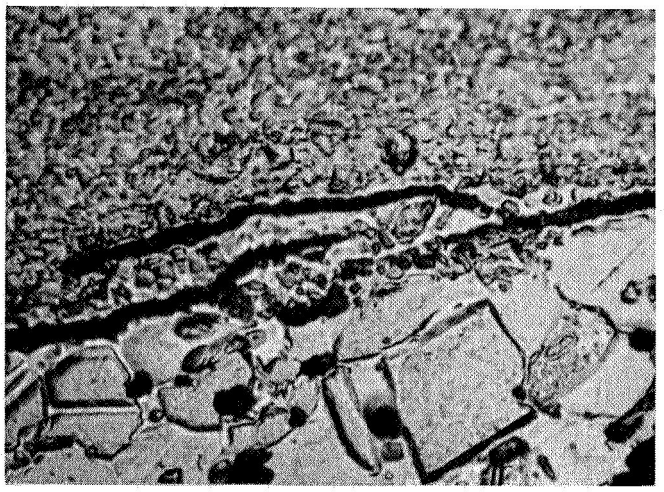


Figure 9 1000X

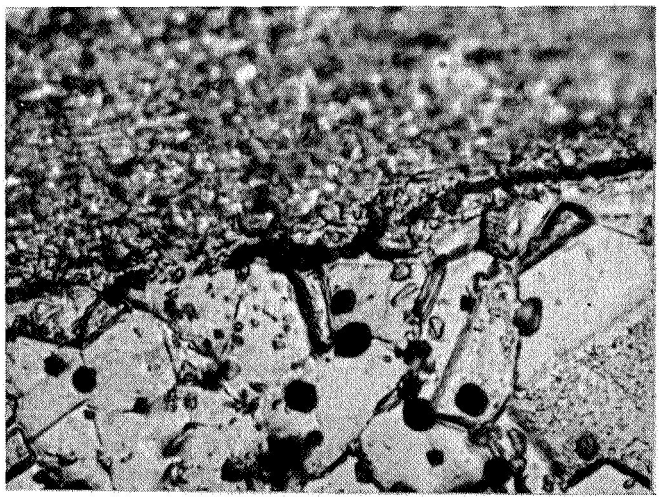


Figure 10 1000X

From large gear of gear assembly 2A-2b.

Photomicrographs of adhered segment material, and of basic annealed gear material.

Hand lapped with 1/4μ diamond and swab etched with Chrome Regia etchant.

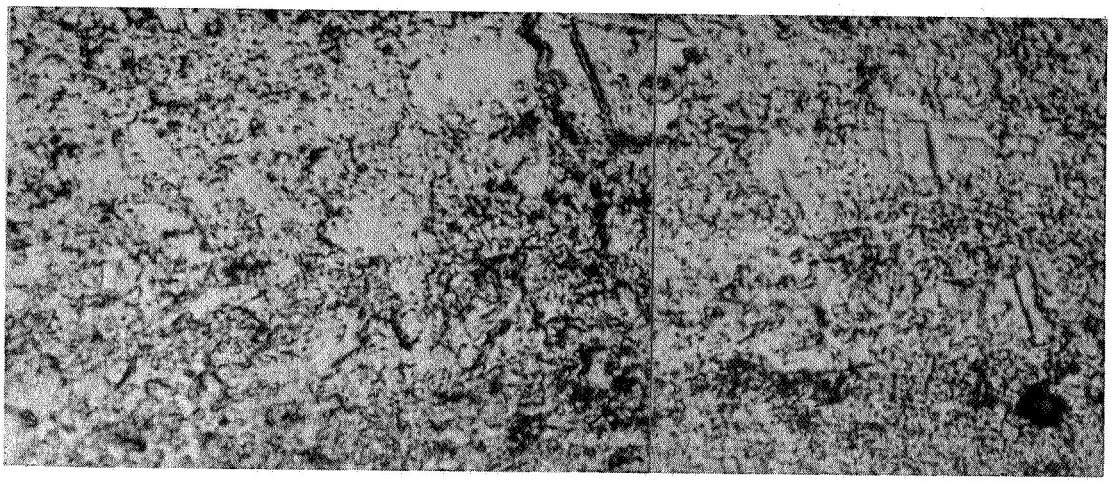


Figure 11 1000X

Typical microstructure of adhered segment material

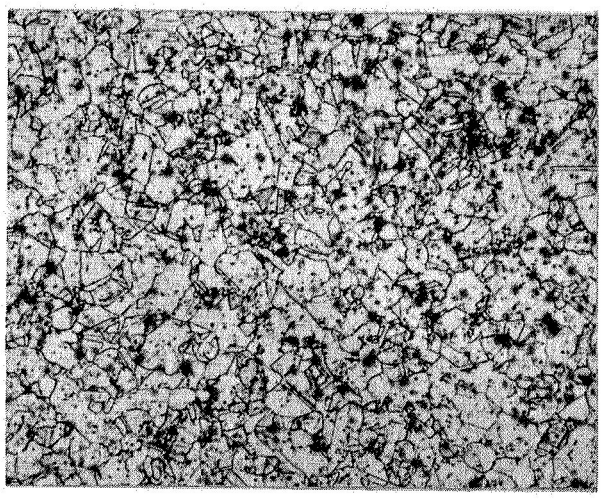


Figure 12 100X

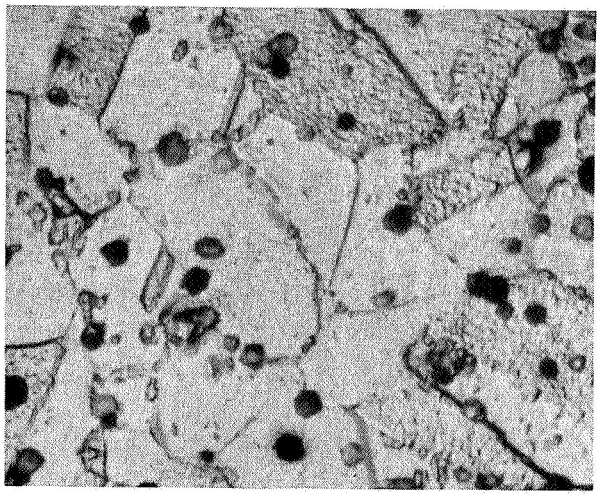


Figure 13 1000X

Typical microstructure of basic gear material, 303 stainless, after annealing

From large gear of gear assembly 2A-2b.

Photomicrographs from gear tooth of small gear in assembly 2A-2c, following heat treatment.

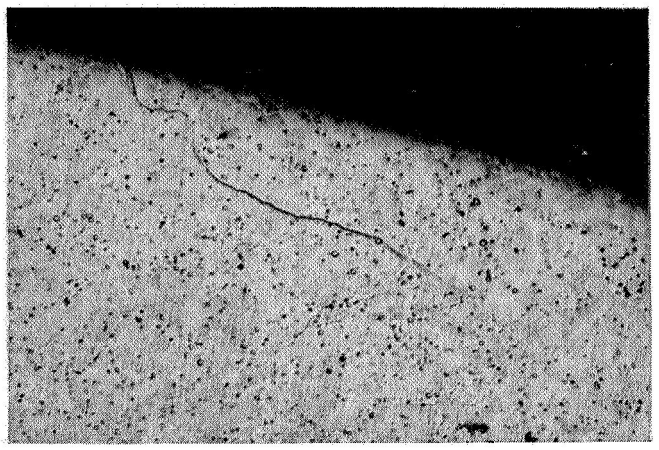


Figure 14 200X

Light Chrome Regia, immersion etch, immediately following final polish on Fisher vibratory automatic polisher. Shows micro fissure which was lost on subsequent polishing and etching operations.

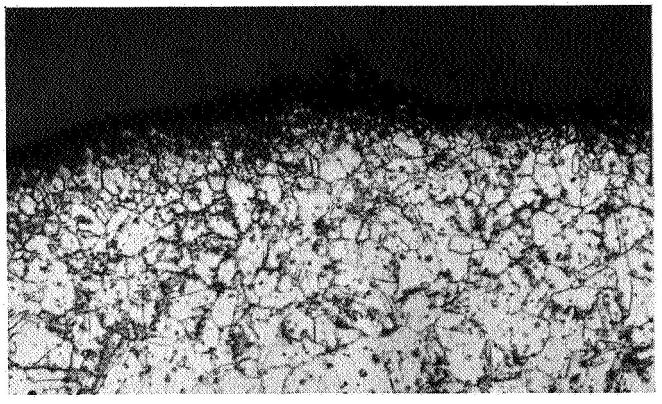


Figure 15 200X

Full etch with Chrome Regia by swabbing, following repolishing and etching operations.

Shows microstructure in area X of enclosure 1, Figure 4.

Post heat treatment photomicrographs.

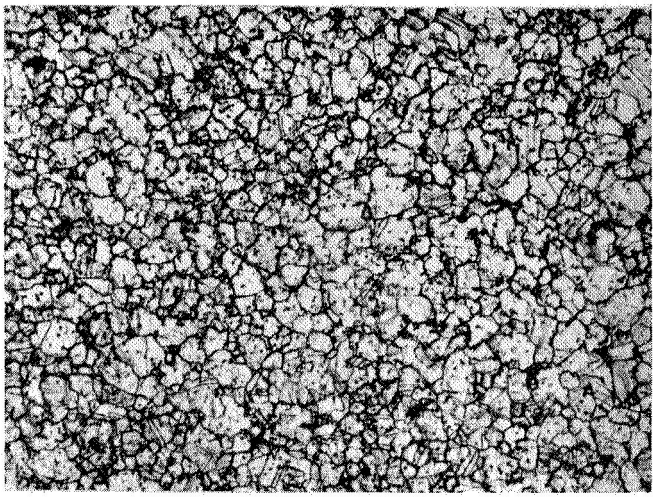


Figure 16 100X

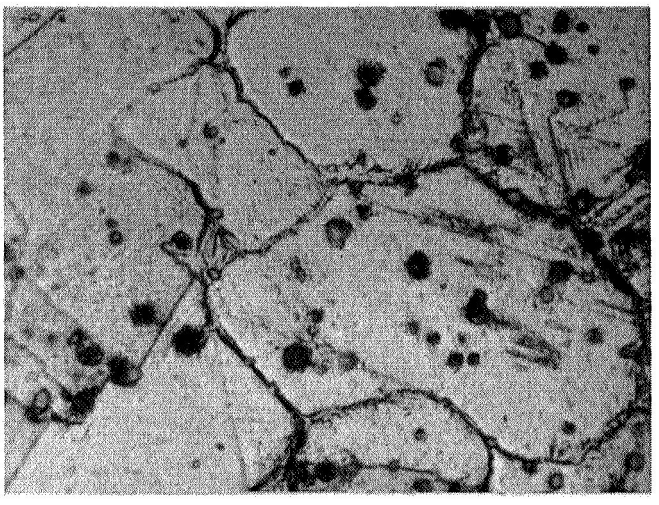


Figure 17 1000X

Typical microstructure of basic gear material from small gear of gear assembly 2A-2c.

Repolished and reetched by swabbing with Chrome Regia.

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	ATD	634-Y03-13	1200-10

CONCLUSIONS:

The gears failed by removal of the protective films – MoS_2, chromium plating and oxides – and subsequent adhesion ("cold welding") of small particles of gear teeth until the particles built-up to a lump large enough to jam the teeth. A great deal of scoring was also experienced.

RECOMMENDATIONS:

It is recommended that the mating steel gears (substrate material) be at least 55 Rc and that the maximum difference between mating gears be no greater than 5 Rc. A heat treatable material should be used such as 400 series (Martensitic SS), nitriding or carburizing steels.

C. E. Vest 12-31-62
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
C. E. Vest	11	S-120	MoS_2 "In Situ"	673Y03-14	1200-41

DATE IN	DATE COMPLETED	PERFORMED BY
3-15-63	9-13-63	W. G. Grenier, J. L. Wall, S. Karpe, R. Swabon and C. E. Vest

NAME OF TEST

Adapting I.B.M. Process of Depositing MoS_2, "In Situ," to Space Applications

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Primary development procedures for adaptation of I.B.M. Process to Space Applications.

EQUIPMENT INVOLVED:

All Metallurgical, Plating, and Conversion Apparatus as described in previous reports as follows:

Service Report on Test Request No. 1200-29, dated 4-15-63
Service Report on Met. Request No. 63-12, dated 9-13-63.

RESULTS:

No Metallography was performed on this Met. Request.

Electrodeposition Results – Surface Appearance, See Table #6.

Electrodeposition Film Thickness, See Figures 1-11 Incl.

MoS_2 "In Situ" Film Thickness, See Figures 12-14 Incl.

W. G. Grenier 11-4-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-5

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "in Situ"	673Y03-14	1200-41

PROCEDURE: It was desired to determine the electrodeposition and conversion parameters for space applications of the IBM MoS_2 "In Situ" process. With an adaptation of this type a large number of variables must necessarily be evaluated. In this particular study the following were unknown:

1. Pre-electrodeposition cleaning methods and solutions for various materials.
2. Correct stripping procedures.
3. Pre-electrodeposition, activation bath; composition, temperature, and exposure times, for the various materials to be coated.
4. Electrodeposition Bath; composition, temperature, and time for the various materials.
5. Procedures for conversion of the MoO_3 complex to MoS_2 "In Situ."

The many experimental procedures to determine the above are submitted here in tabular form on Sheets 3 - 16 inclusive, Tables 1 - 7 inclusive.

W. G. Grenier 11-4-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-5

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #1 - Cleaning Methods Defined

Method No.	Cleaning Solutions			Rinse Method	Dry Method
	Type	Method of Use	Time Minutes		
1	Trichloroethane	Ultrasonic	5		Air Dry
2	Trichloroethane	Dip	-	Tap water followed by distilled water	Air Dry
3	Polish through 400 grit paper		-	Tap water followed by Ethyl Alcohol	Air Dry
4	Detergent and Water	Ultrasonic	3	Warm tap water	Alcohol and Air
5	Hot Soapy Distilled Water	Nylon Brush	-	Distilled Water	Alcohol and Air
6	Vapor honed with 325 mesh			Al_2O_3	-
7	Vapor honed with 325 mesh			Glass Beads	-
8	Benzene	Ultrasonic	2	-	Air Dry
9	Polish through 320 grit paper			Water - Alcohol	Air Dry
10	Polish through 600 grit paper			Water - Alcohol	Air Dry

Table No. 2
Stripping Procedures, Defined

Method No.	Solution Composition	Condition of Use	Method of Use	Time (Min.)	Rinse
1	10% NaOH	Boiling	Immersion	5	Tap followed by distilled water
2	50% HNO_3	R.T.	Immersion	3	Tap followed by distilled water
3	20% H_2SO_4	180°F	Electrolytic 200 ma/in^2	1	Immerse in Solution #6, Table #3
4	35% HNO_3	R.T.	Immersion	3	Distilled water

W. G. Grenier 11-4-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-5

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #3 - Activation Baths and Procedures, Defined

Method No.	Bath Composition	Bath		Procedure
		Temp.	Time (Min.)	
1	10 v/o HCl + 10 v/o HNO_3 + 80 v/o H_2O	R.T.	3	Immersion
2	50 v/o HNO_3 + 50 v/o H_2O	R.T.	3	Immersion
3	10 v/o NaOH + 90 v/o H_2O	80°C	5	Immersion
4	2 v/o HF + 20 v/o HCl + 78 v/o H_2O	R.T.	2	Immersion
5	5ml HCl + 2 ml Picric + 100 ml Ethyl alcohol	R.T.	2	Immersion
6	0.1 v/o HCl + 1.0 v/o H_2SO_4 + 98.9 v/o H_2O	R.T.	1/2	Immerse and Rinse in hot distilled H_2O
7	20 v/o H_2SO_4 + 80 v/o H_2O	R.T.	1	Electrolytic: 8.7 ma/in^2
8	50 v/o HCl + 50 v/o H_2O	R.T.	5	Electrolytic:3 volts
9	20 v/o H_2SO_4 + 80 v/o H_2O	R.T.	5	Electrolytic:3 volts
10	20 v/o HCl + 80 v/o H_2O	R.T.	5	Electrolytic:3 volts
11	20 v/o NaOH + 80 v/o H_2O	80°C	5	Immerse and Rinse in hot distilled H_2O
12	20 v/o H_2SO_4 + 80 v/o H_2O	R.T.	2	Immerse and Rinse in hot distilled H_2O
13	20 v/o H_2SO_4 + 80 v/o H_2O	150°F	1	Immersion
14	20 v/o H_2SO_4 + 80 v/o H_2O	180°F	1/2	Immersion
15	50 v/o H_2SO_4 + 50 v/o H_2O	180°F	2	Immersion
16	20 v/o H_2SO_4 + 80 v/o H_2O	180°F	1	Immersion

Note: H_2O is distilled water unless otherwise noted.

W. G. Grenier 11-4-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-5

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #4 - Electrodeposition Baths, Compositions and Other Information

Bath No.	Composition				Annode Material	Bath Agitation Source
	NH_4COOH (gms)	$MoO_2 \cdot H_2O$ (gms)	85% MoO_3 (gms)	Distilled H_2O (ml)		
1	54.6	12.6	---	1000	Platinum	Fisher Propeller
2	54.6	12.6	1.0	1000	Platinum	Fisher Propeller
3	54.6	---	12.6	1000	Platinum	Fisher Propeller
4	54.6	---	12.6	1000	Platinum	Tempco Magnastir
5	109.2	---	25.2	2000	Platinum	Tempco Magnastir

W.G. Grenier 11-4-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-5

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #5 - Electrodeposition, experimental Trials Defined (Page 1 of 6)

Trial No.	Substrate Material	Specimen Preparation Method and Solution No.				Electrodeposition			Remarks
		Clean Table 1	Strip Table 2	Activate Table 3	Deposit Bath Table 4	Time (Min.)	Temp.	Current Density ma/in^2	
1	6061 Al	1	1	1	1	6	50°-60°C	120	Same specimen recleaned between runs as indicated
1	6061 Al	2	-	-	1	12	60°-72°C	120	
1	6061 Al	2	-	-	1	6	82°C	120	
2	6061 Al	-	1	-	2	6	-	120	Film: Powdery and Adherent
3	6061 Al	1	1	2	1	20	160°F	120	
3	6061 Al	1	1	2	1	30	160°F	120	
3	6061 Al	1	1	2	1	40	160°F	120	
4	6061 Al	1 & 3	-	3	1	10	160°F	120	
4	6061 Al	1 & 3	-	3	1	20	160°F	120	
4	6061 Al	1 & 3	-	3	1	30	160°F	120	
4	6061 Al	1 & 3	-	3	1	40	160°F	120	
5	6061 Al	3	-	3	1	5	160°F	120	
5	6061 Al	3	-	3	1	10	160°F	120	
5	6061 Al	3	-	3	1	15	160°F	120	Film: Nonuniform and Powdery
5	6061 Al	3	-	3	1	20	160°F	120	
5	6061 Al	3	-	3	1	25	160°F	120	
5	6061 Al	3	-	3	1	30	160°F	120	
6	440C, S.S.	1	-	4	1	15	160°F	120	Film nonuniform and flaky

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #5 - Electrodeposition, experimental Trails Defined (Page 2 of 6)

Trial No.	Substrate Material	Specimen Preparation Method and Solution No.				Electrodeposition			Remarks
		Clean Table 1	Strip Table 2	Activate Table 3	Deposit Bath Table 4	Time (Min.)	Temp.	Current Density ma/in.^{2}	
7	440C, S.S.	1	-	5	1	15	160°F	120	Film nonuniform and flaky
8	M-10 Tool Steel	1	-	5	1	15	160°F	120	Film nonuniform and flaky
9	M-10 Tool Steel	1	-	4	3	5	160°F	120	
9	M-10 Tool Steel	1	-	4	3	10	160°F	120	
9	M-10 Tool Steel	1	-	4	3	20	160°F	120	Film: Black and uniform with good adherence
9	M-10 Tool Steel	1	-	4	3	30	160°F	120	
9	M-10 Tool Steel	1	-	4	3	50	160°F	120	
10	440C, S.S.	5 & 1	3	6	3	12	R.T.	120	Good Film
11	416 S.S. Pic gears	5 & 1	3	6	3	12	R.T.	120	Film: Gray, grainy, uniform
12	440C, S.S. Bearings	5 & 1	3	6	3	12	R.T.	120	Film: Nonadherent in spots
13	440C, S.S. Bearings	4 & 1	3	6	3	12	R.T.	120	

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M.R. 63-5

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #5 - Electrodeposition, Experimental Trials Defined (Page 3 of 6)

Trial No.	Substrate Material	Specimen Preparation Method and Solution No.				Electrodeposition			Remarks
		Clean Table 1	Strip Table 2	Activate Table 3	Deposit Bath Table 4	Time (Min.)	Temp.	Current Density ma/in.^{2}	
14	440C, S.S.	4 & 1	3	6	3	12	R.T.	120	Thoroughly air dried and then converted
15	316 S.S.	5 & 1	-	7	3	12	R.T.	120	Conversion Specimen
16	440C, S.S., M-10, Steel	5 & 1	-	7	3	12	R.T.	120	Film: Reasonably adherent
17	M-10 Tool Steel	5 & 1	-	8	3	18	R.T.	120	Film: Glossy and solid
18	M-10 Tool Steel	5 & 1	-	8	3	18	R.T.	120	Film: Poor adherence, dull and grainy
19	316 S.S.	5 & 1	-	9	3	12	R.T.	120	Film looked very good
20	316 S.S.	5 & 1	-	10	3	18	R.T.	120	Film looked very good
21	416 S.S.	5 & 1	-	10	3	18	R.T.	120	Film: Dull, black, flaky
22	6061 Al	3 & 1	-	11	3	12	R.T.	120	
23	416 S.S.	4 & 1	-	7	3	18	R.T.	120	Film: Dull, black, some nonadherent

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #5 - Electrodeposition, Experimental Trials Defined (Page 4 of 6)

Trial No.	Substrate Material	Specimen Preparation Method and Solution No.				Electrodeposition			Remarks
		Clean Table 1	Strip Table 2	Activate Table 3	Deposit Bath Table 4	Time (Min.)	Temp.	Current Density ma/in.^{2}	
24	440C, S.S.	5 & 1	4	12	3	6	R.T.	120	
24	440C, S.S.	5 & 1	4	12	3	18	R.T.	120	
25	440C, S.S.	1	-	13	3	18	180°F	120	Film: Flaky
25	440C, S.S.	1	-	13	3	6	180°F	120	Film: Good - Adherent
25	440C, S.S.	1	-	13	3	10	180°F	120	Film: Flaky
25	440C, S.S.	1	-	13	3	12	180°F	120	Film: Flaky
26	440C, S.S.	1	-	13	3	12	R.T.	120	Film: Dull - black, where hot bath had glossy coating. (Max. time for gears to be 10 minutes.)
26	440C, S.S.	1	-	13	3	6	R.T.	120	
26	440C, S.S.	1	-	13	3	10	R.T.	120	
27	416 S.S. Gears	1	-	14	3	10	R.T.	120	
28	Timken Rings	1	-	14	5	10	R.T.	120	Uncoated areas were protected with Glyptol
29	416 S.S. Gears	5 & 1	-	14	5	10	R.T.	120	Film: Satisfactory
30	2024 Al Gears	1	-	11	5	10	R.T.	120	Film: Satisfactory

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #5 - Electrodeposition, Experimental Trials Defined (Page 5 of 6)

Trial No.	Substrate Material	Specimen Preparation Method and Solution No.				Electrodeposition			Remarks
		Clean Table 1	Strip Table 2	Activate Table 3	Deposit Bath Table 4	Time (Min.)	Temp.	Current Density ma/in.^{2}	
31	6061 Al	1	-	11	5	10	R.T.	120	Film: Satisfactory
32	Timken Rings	6	-	-	5	10	R.T.	120	Film: Satisfactory
33	Timken Rings	7	-	-	5	10	R.T.	120	Same as 32
34	316 S.S.	3,4 & 8	-	13	5	3	R.T.	120	Submitted to Fabrication Division for Electronic Measurement of deposit film thickness.
34	316 S.S.	3,4 & 8	-	13	5	6	R.T.	120	
34	316 S.S.	3,4 & 8	-	13	5	9	R.T.		
34	316 S.S.	3,4 & 8	-	13	5	12	R.T.	120	
34	316 S.S.	3,4 & 8	-	13	5	15	R.T.	120	
34	316 S.S.	3,4 & 8	-	13	5	18	R.T.	120	
35	440C, S.S.	4 & 8	-	15	5	3	R.T.	120	Mounted in glass filled epoxy for optical measurement of deposit film thickness.
35	440C, S.S.	4 & 8	-	15	5	6	R.T.	120	
35	440C, S.S.	4 & 8	-	15	5	9	R.T.	120	
35	440C, S.S.	4 & 8	-	15	5	12	R.T.	120	
35	440C, S.S.	4 & 8	-	15	5	15	R.T.	120	

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C.E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #5 - Electrodeposition, Experimental Trials Defined (Page 6 of 6)

Trial No.	Substrate Material	Specimen Preparation Method and Solution No.				Electrodeposition			Remarks
		Clean Table 1	Strip Table 2	Activate Table 3	Deposit Bath Table 4	Time (Min.)	Temp.	Current Density ma/in.^{2}	
36	410 S.S.	4 & 8	-	16	5	3	R.T.	120	6 specimens coated for each time period, 3 each were mounted as in Trial No. 35 for deposit thickness, values.
36	410 S.S.	4 & 8	-	16	5	6	R.T.	120	
36	410 S.S.	4 & 8	-	16	5	9	R.T.	120	
36	410 S.S.	4 & 8	-	16	5	12	R.T.	120	
36	410 S.S.	4 & 8	-	16	5	15	R.T.	120	
37	410 S.S.	9,4,8	-	16	5	9	R.T.	120	2 specimens coated for each time period, 1 for conversion and 1 for film thickness determinations.
37	410 S.S.	9,4,8	-	16	5	12	R.T.	120	
37	410 S.S.	9,4,8	-	16	5	15	R.T.	120	
38	304 S.S.	9,4,8	-	16	5	3	R.T.	120	2 specimens coated for each time period for film thickness determinations.
38	304 S.S.	9,4,8	-	16	5	9	R.T.	120	
38	304 S.S.	9,4,8	-	16	5	12	R.T.	120	
39	Copper	9,4,8	-	2	5	3	R.T.	120	Same as Trial No. 38.
39	Copper	9,4,8	-	2	5	9	R.T.	120	
39	Copper	9,4,8	-	2	5	12	R.T.	120	

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #6 - Electrodeposition Results (Page 1 of 3)

Table 5 Trial No.	Substrate Material	Deposit Thickness Measuring Method	Deposition		Surface Appearance
			Time (Min.)	Thickness Ins. $\times 10^{-6}$	
1	6061 Al	Micrometer	6	0	
1	6061 Al	Calipers	18	50	Sooty black on annode face and metallic on opposite face.
1	6061 Al		24	150	
2	6061 Al	Micrometer Calipers	6	0	Powdery & adherent but not measureable.
3	6061 Al	Micrometer	20	100	
3	6061 Al	Calipers	30	300	
3	6061 Al		40	400	
4	6061 Al	Micrometer	10	0	
4	6061 Al	Calipers	20	100	
4	6061 Al		30	417	
4	6061 Al		40	400	
5	6061 Al	Filar Micrometer	5	557	Non uniform & powdery
5	6061 Al	Microscope	10	488	
5	6061 Al		15	586	
5	6061 Al		20	704	
5	6061 Al		25	878	
5	6061 Al		30	807	
9	M-10 Tool steel	Micrometer Calipers	5	67	Black & Uniform
9			10	67	
9			20	150	
9			30	233	
9			50	200	

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #6 - Electrodeposition Results (Page 2 of 3)

Table 5 Trial No.	Substrate Material	Deposit Thickness Measuring Method	Deposition (Min.)	Deposition Thickness Ins. $\times 10^{-6}$	Surface Appearance
34	316 S.S.	Electronically	3	130	Black & Uniform
34	316 S.S.	by	6	167	
34	316 S.S.	Fabrication	9	201	
34	316 S.S.	Division	12	220	
34	316 S.S.		15	255	
34	316 S.S.		18	248	
35	440C, S.S.	Filar Micrometer	3	160	
35	440C, S.S.	Microscope	6	258	
35	440C, S.S.		9	378	
35	440C, S.S.		12	350	
35	440C, S.S.		15	386	
36	410 S.S.	Filar Micrometer	3	85	3 Specimens for each deposition time were mounted for optical measurement of film thickness. Values given are numerical averages for the 3 specimens.
36	410 S.S.	Microscope	6	124	
36	410 S.S.		9	160	
36	410 S.S.		12	206	
36	410 S.S.		15	203	
36	410 S.S.	Electronically	3	52	3 specimens for each deposition time period as above, but not mounted.
36	410 S.S.	by	6	145	
36	410 S.S.	Fabrication	9	280	
36	410 S.S.	Division	12	283	
36	410 S.S.		15	128	
37	410 S.S.	Filar Micrometer	9	160	Surface: Good on all specs. Thickness values are averages for 3 specimens at each deposition time.
37	410 S.S.	Microscope	12	201	
37	410 S.S.		15	259	
37	410 S.S.	Electronically	9	258	
37	410 S.S.	by	12	307	
37	410 S.S.	Fabrication	15	358	
		Division			

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #6 - Electrodeposition Results (Page 3 of 3)

Table 5 Trial No.	Substrate Material	Deposit Thickness Measuring Method	Deposition (Min.)	Deposition Thickness Ins. $\times 10^{-6}$	Surface Appearance
38	304 S.S.	Filar Micrometer	3	215	Surfaces: Good. Values are averages for 2 specimens at each time.
38	304 S.S.	Microscope	9	380	
38	304 S.S.		12	372	
39	Copper	Filar Micrometer	3	160	Same as Trial No. 38.
39	Copper	Microscope	9	283	
39	Copper		12	426	

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #7 - Conversion of Mo Complex to MoS_2 "in situ" Processes (Page 1 of 2)

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Table #7 - Conversion of Mo Complex (Page 2 of 2)

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 "In Situ"	673Y03-14	1200-41

DATA: Electrodeposited Mo Complex on 6061 Al as Table #5 - Trial No. 4
Electrodeposition Time Compared to Resultant Film Thickness

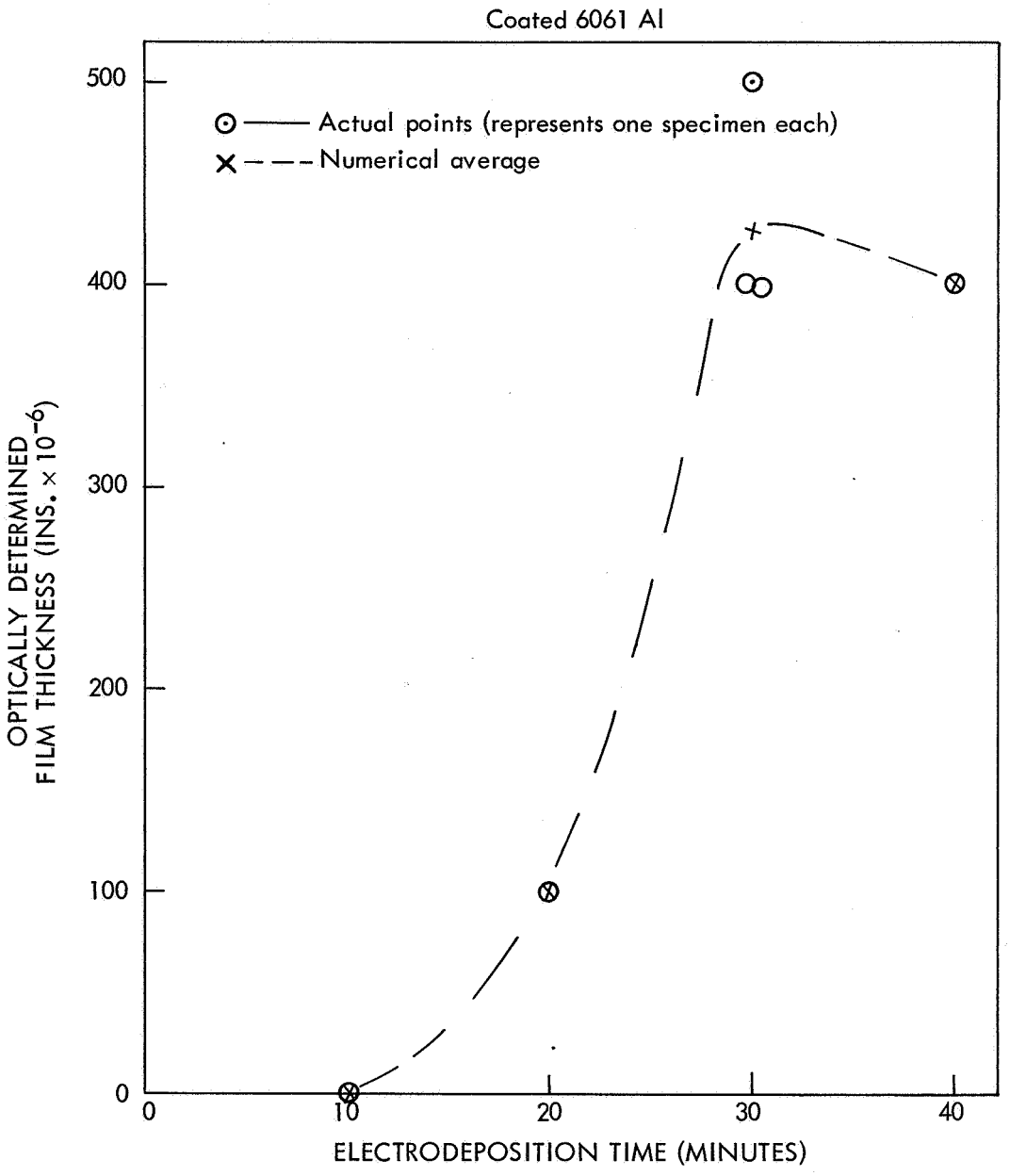

Figure 1

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 "In Situ"	673Y03-14	1200-41

DATA: Electrodeposited Mo Complex on 6061 Al as Table #5 - Trial #5
Electrodeposition Time Compared With Resultant Film Thickness Contd.

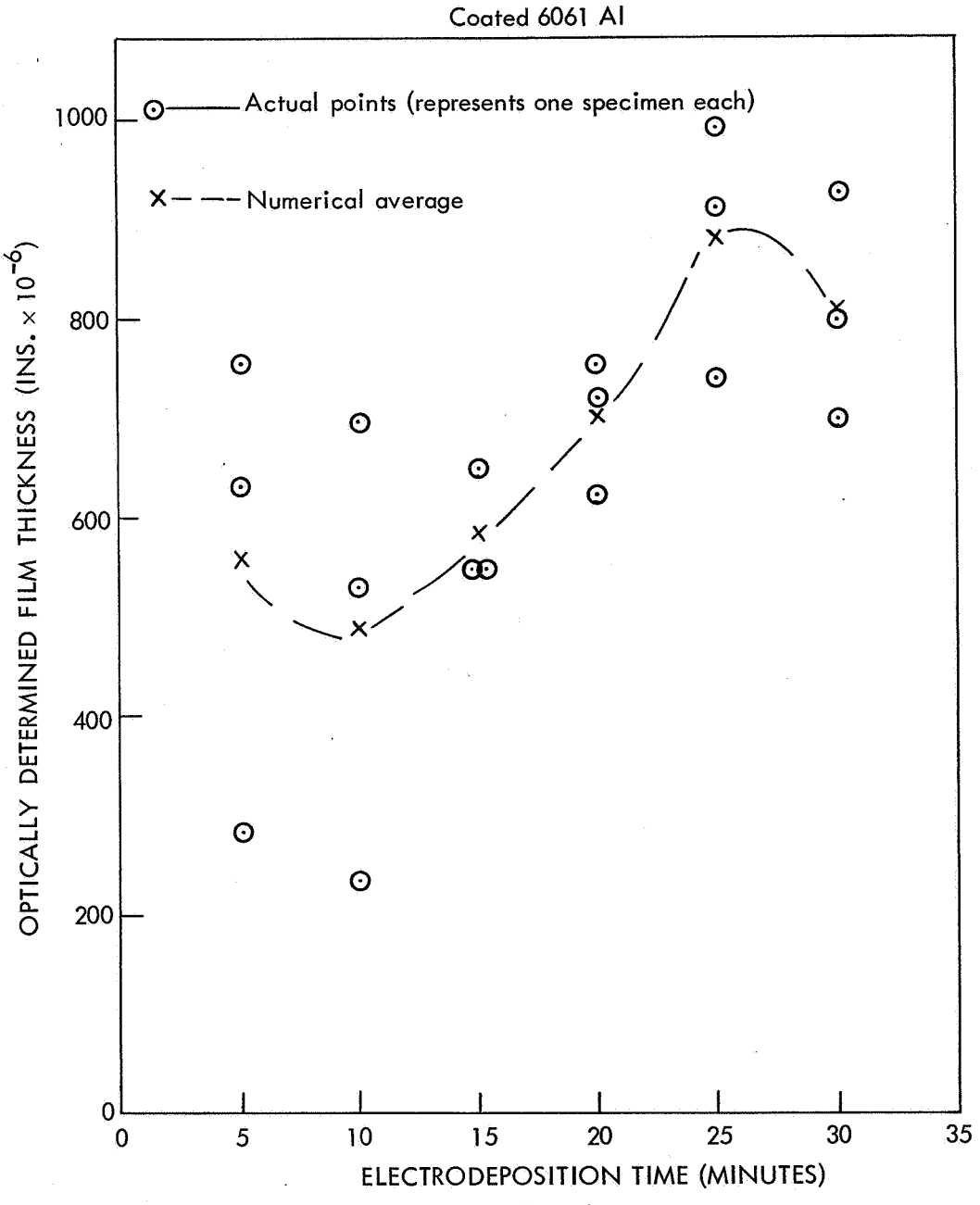

Figure 2

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 "In Situ"	673Y03-14	1200-41

DATA: Electrodeposited Mo Complex on M-10 Tool Steel, as Table #5 Trial #9 Electrodeposition Time Compared with Resultant Film Thickness, Contd.

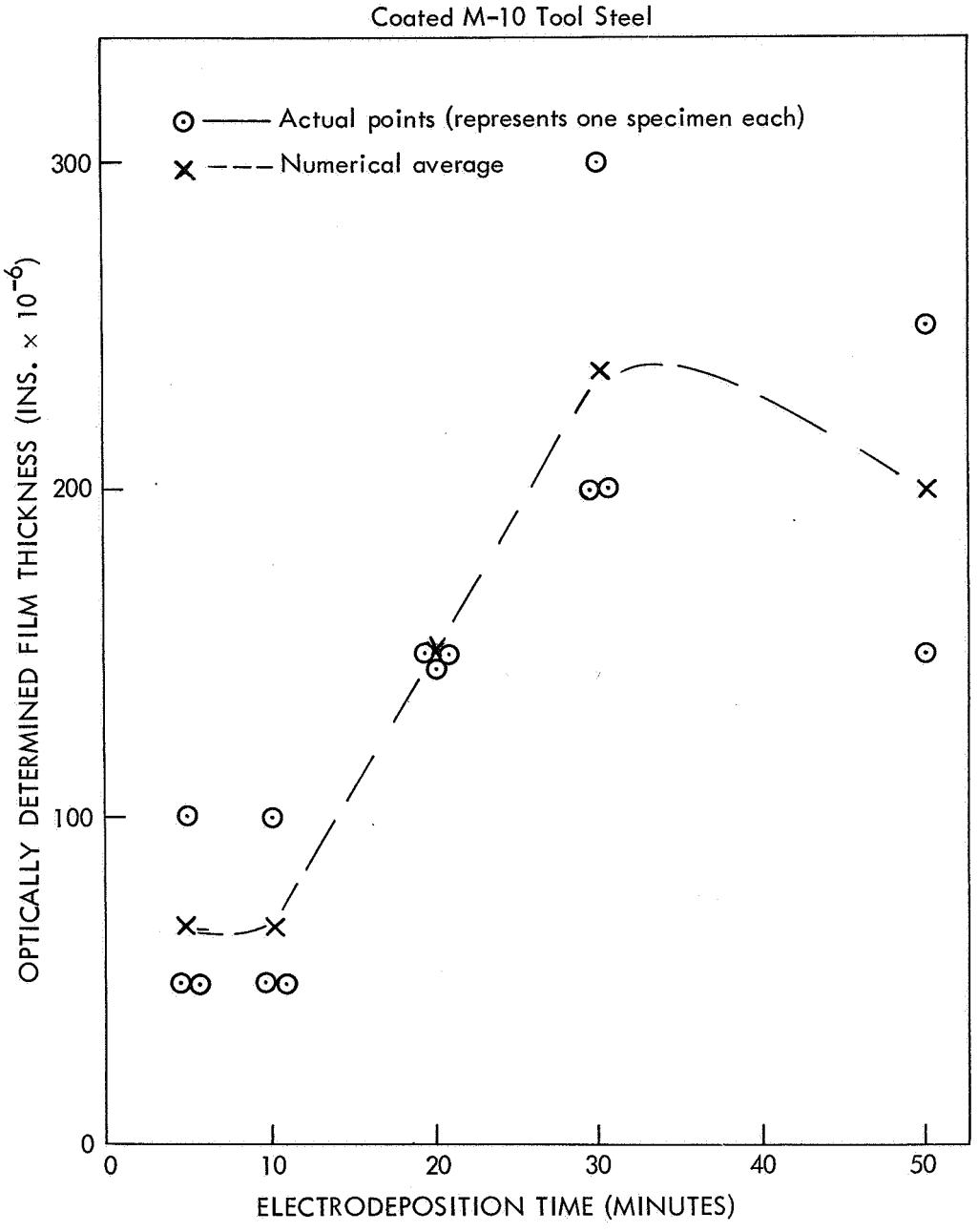

Figure 3

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 "In Situ"	673Y03-14	1200-41

DATA: Electrodeposited Mo Complex on 316 S.S. as Table #5 - Trial #34
Electrodeposition Time, Compared with Film Thickness, Contd.

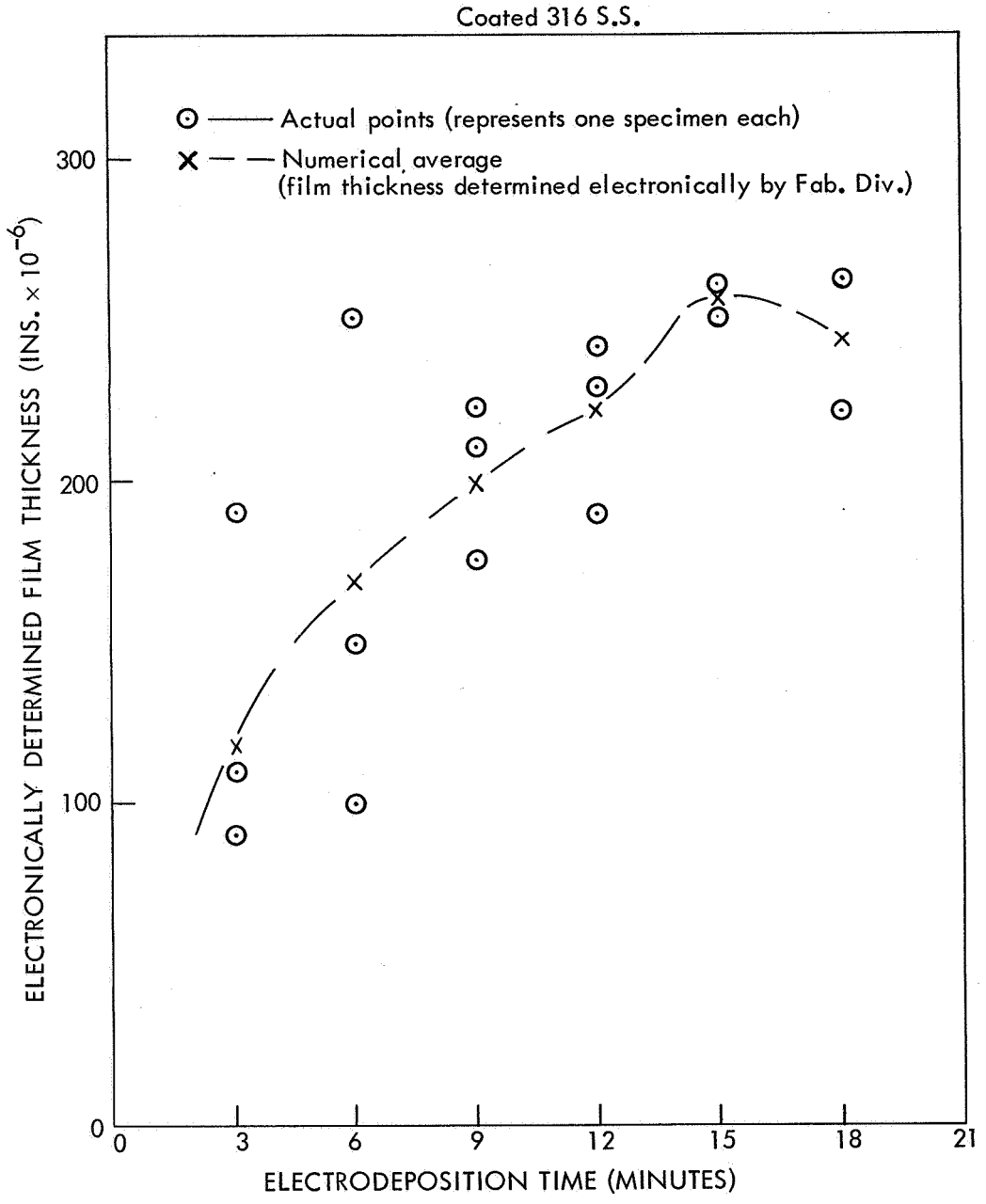

Figure 4

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	Mo S_2 "In Situ"	673Y03-14	1200-41

DATA: Electrodeposited Mo Complex on 440 c, S.S., as Table #5 - Trial #35 Electrodeposition Time, Compared with Film Thickness, Contd.

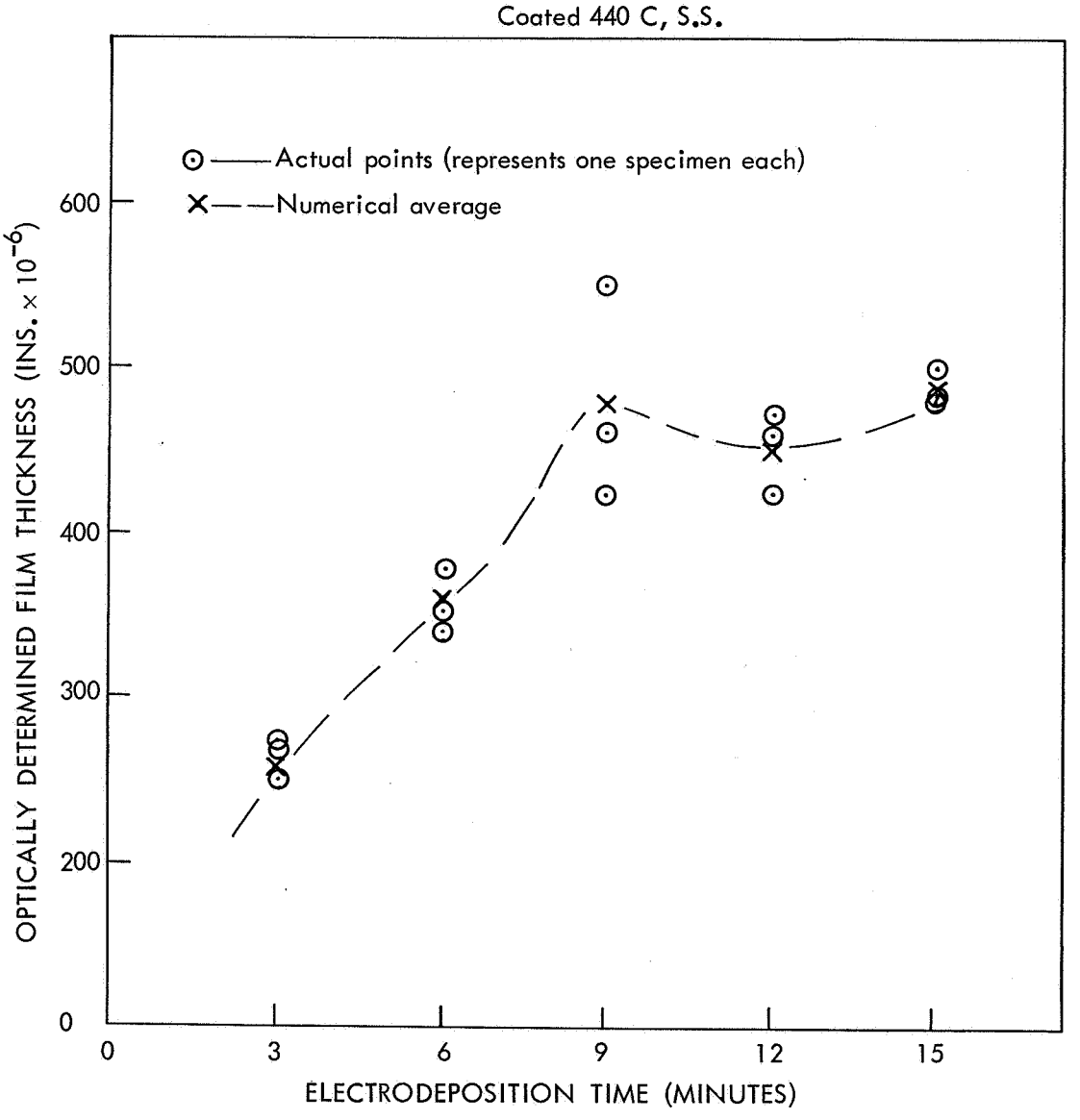

Figure 5

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Electrodeposited Mo Complex on 410 S.S., As Table #5 - Trial #36
Electrodeposition Time, Compared with Film Thickness, Continued.

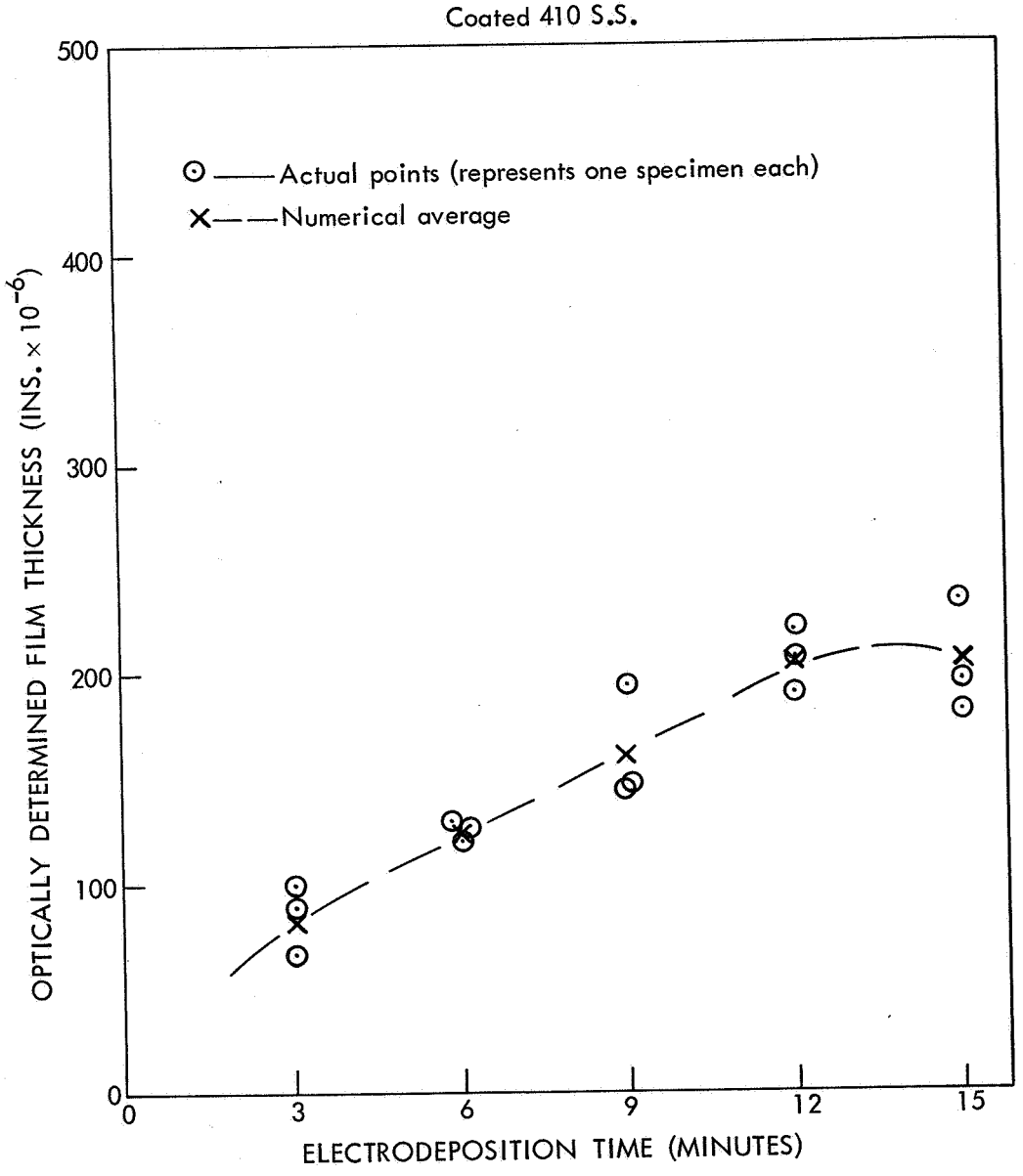

Figure 6

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Electrodeposited Mo Complex on 410 S. S. As Table #5 - Trial #36
Electrodeposition Time Compared with Film Thickness, Continued

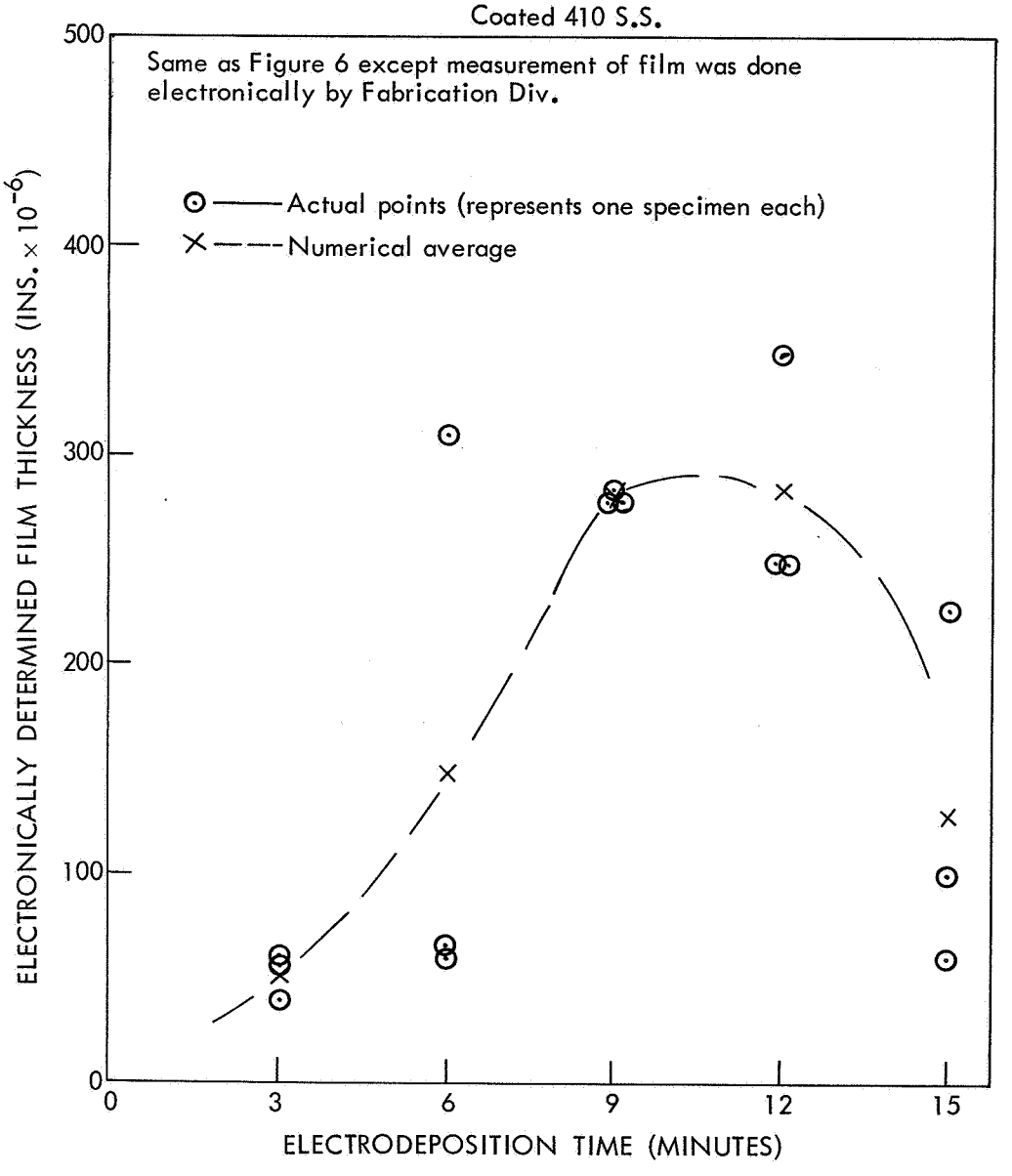

Figure 7

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Electrodeposited Mo Complex on 410 S. S., As Table #5 - Trial #37
Electrodeposition Time Compared with Film Thickness, Continued.

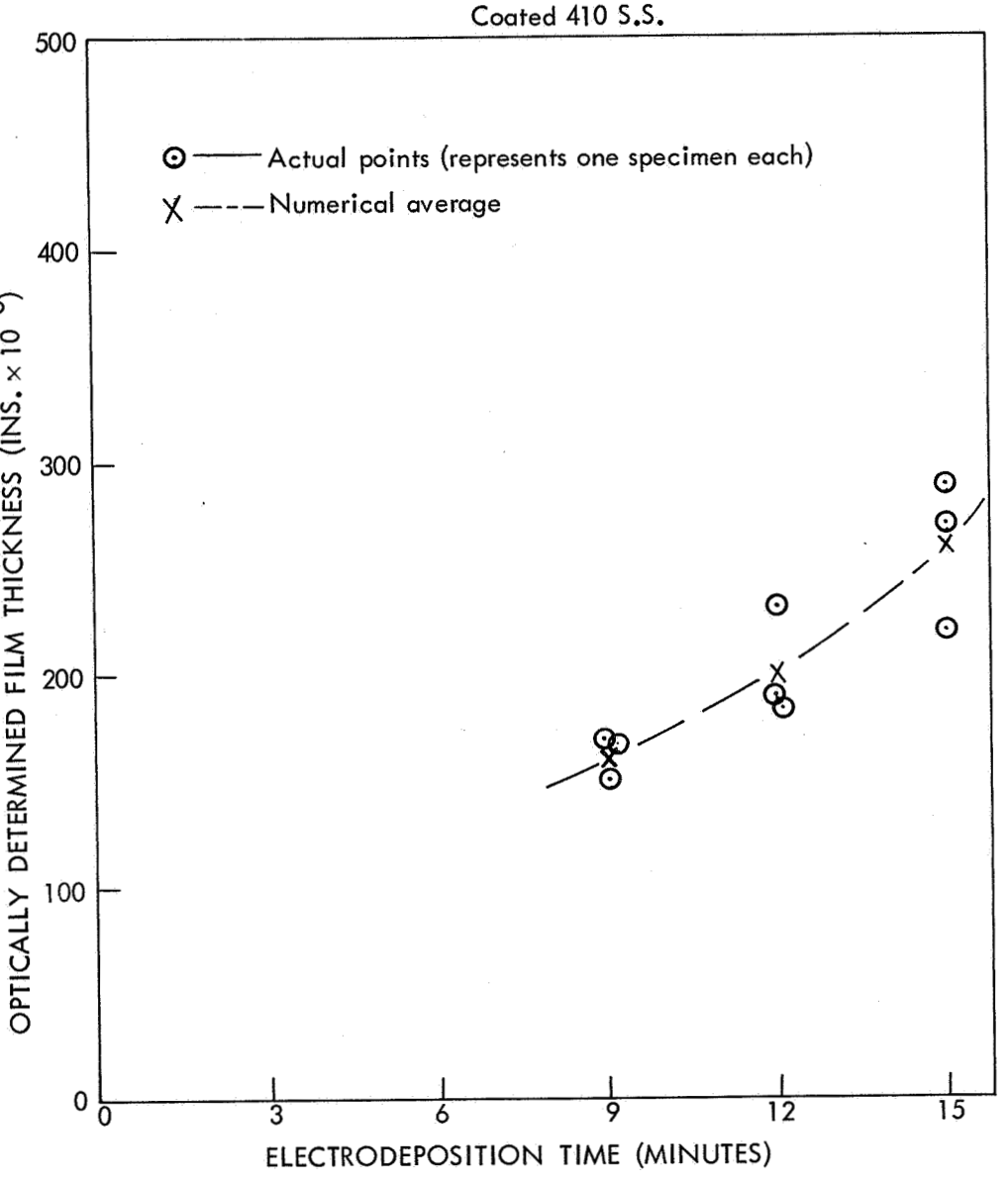

Figure 8

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Electrodeposited Mo Complex on 410 S. S., As Table #5 - Trial #37
Electrodeposition Time Compared with Film Thickness, Continued

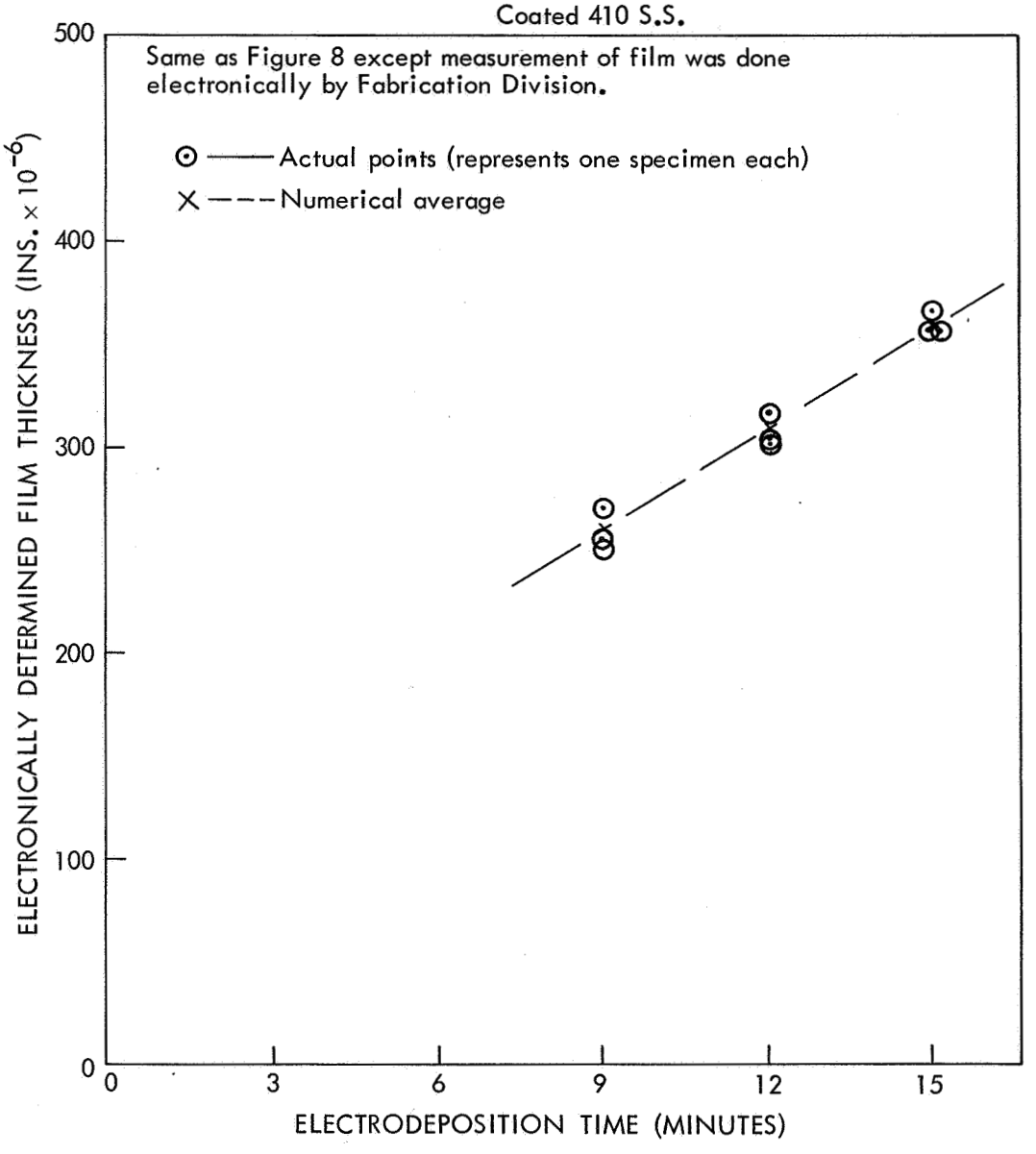

Figure 9

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Electrodeposited Mo Complex on 304 S. S., As Table #5 - Trial #38
Electrodeposition Time Compared with Film Thickness, Continued

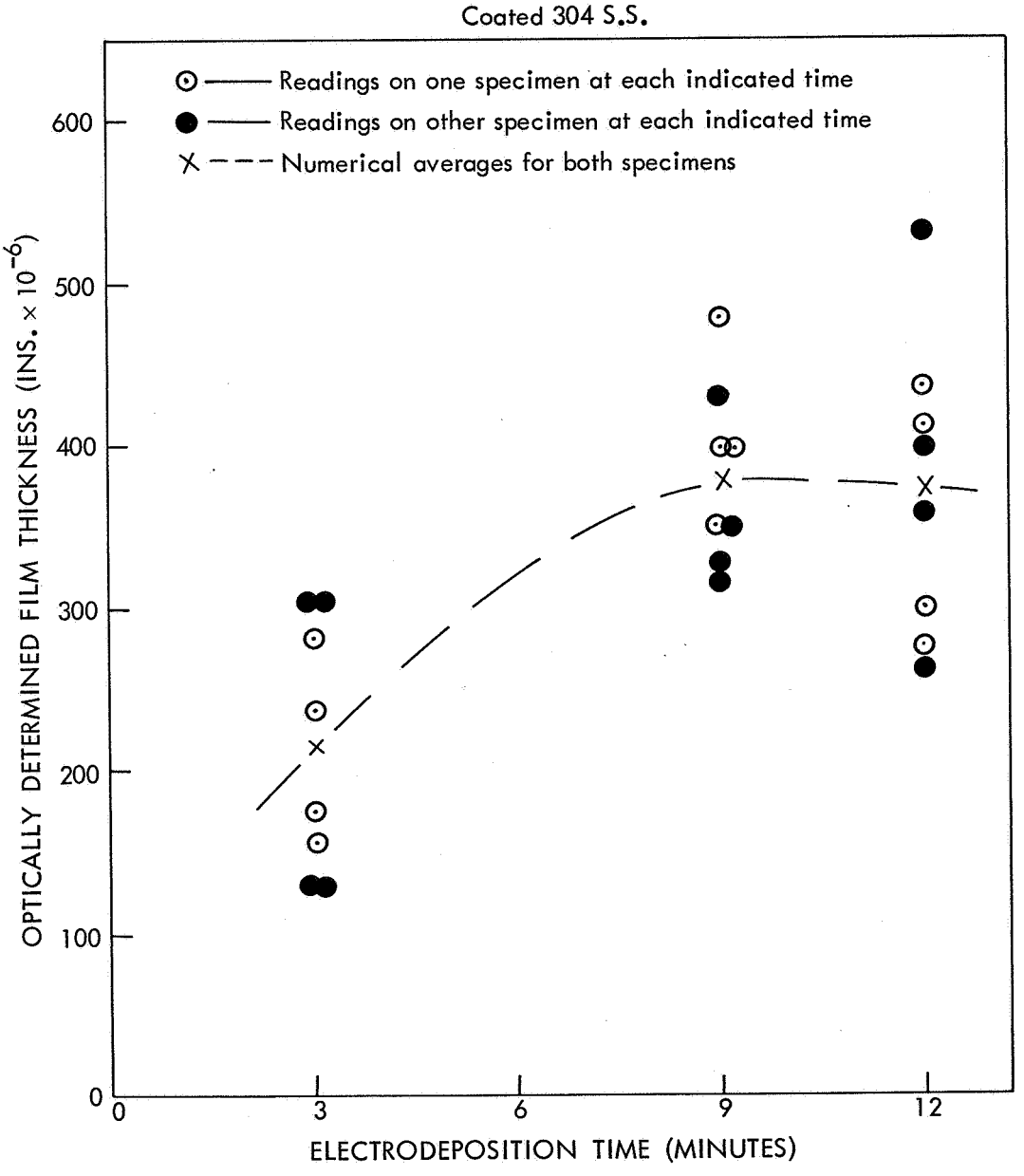

Figure 10

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ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: Electrodeposited Mo Complex on Copper, As Table #5 - Trial #39
Electrodeposition Time Compared with Film Thickness, Continued.

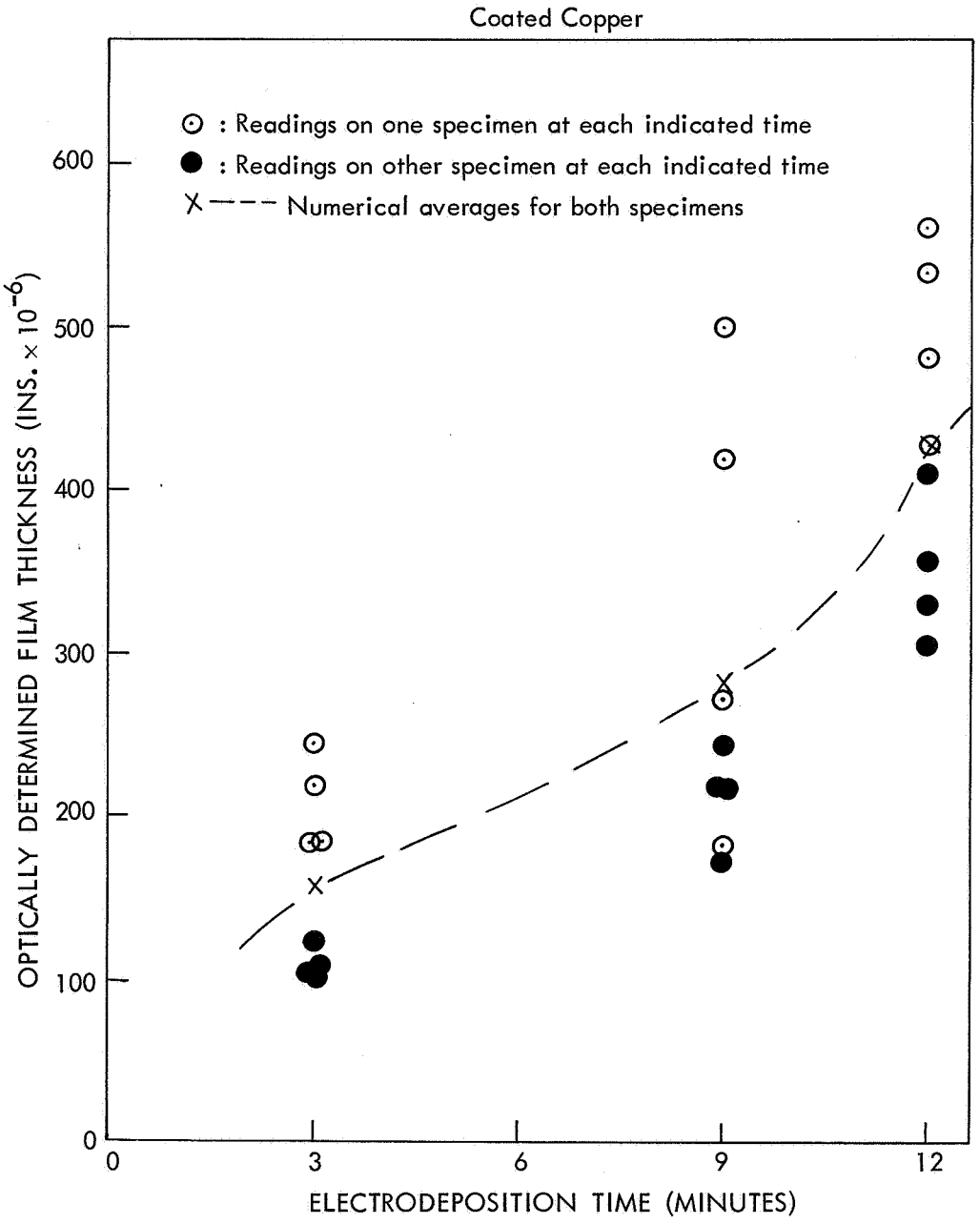

Figure 11

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STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-5

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: MoS_2 "In Situ" on 410 S. S., As Table #7 - Process #21 -- Thickness of Converted Film Compared with Various Mo Complex Electrodeposition Times

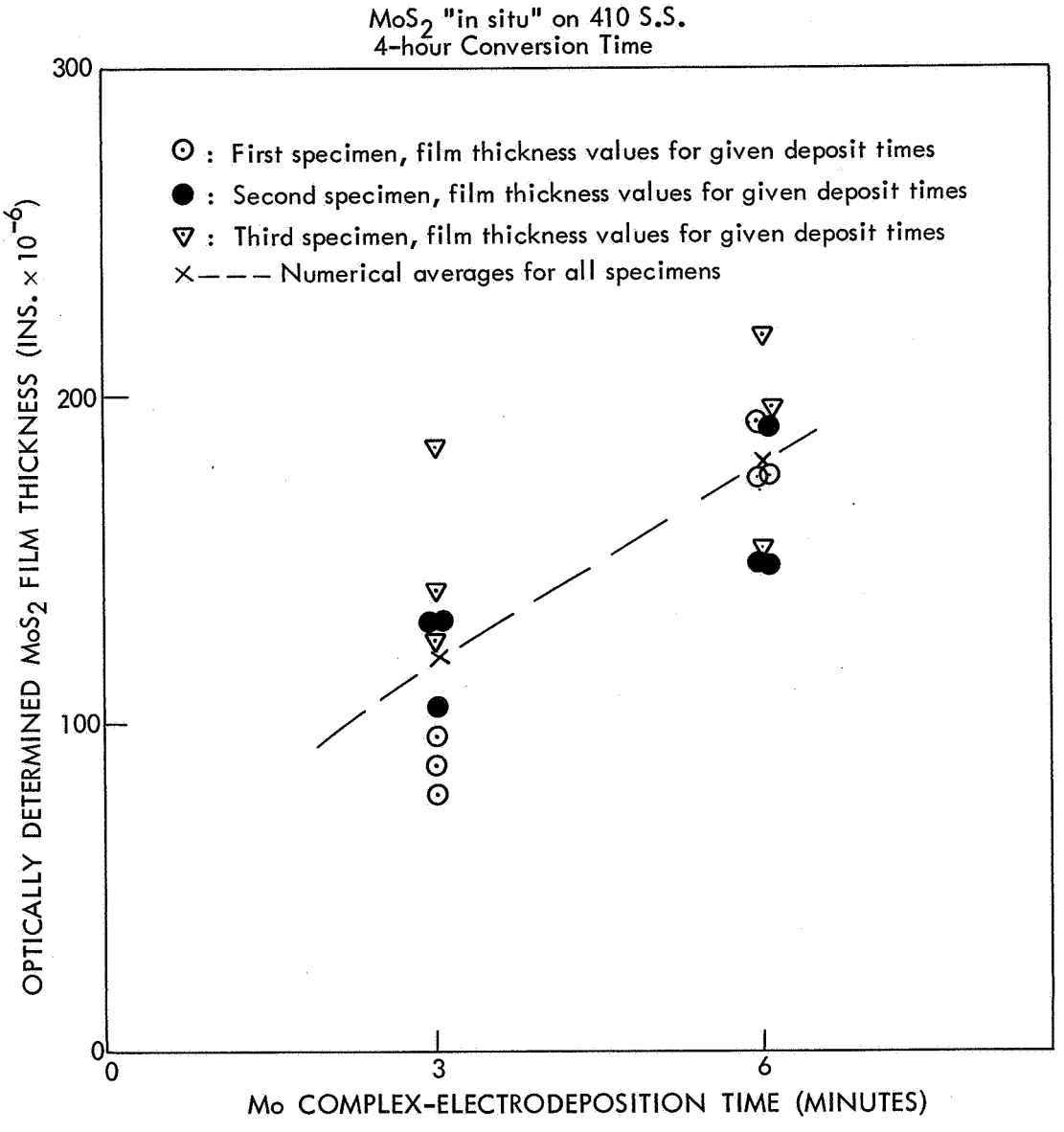


Figure 12

W. G. Grenier 11-4-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-5

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: MoS_2 "In Situ" on 410 S.S., As Table #7 - Process #22 -- Thickness of Converted Film Compared with Various Mo Complex Electrodeposition Times

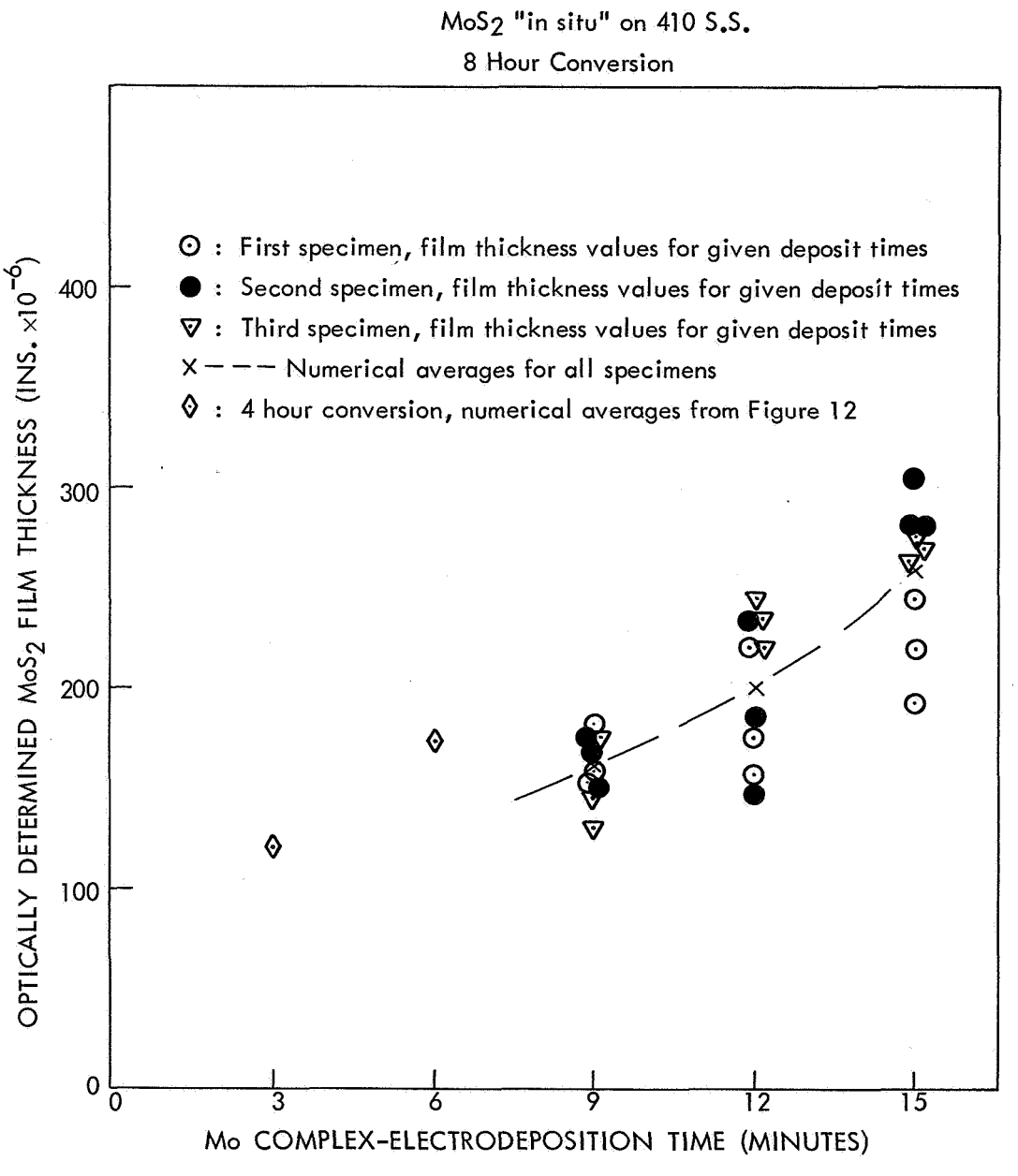


Figure 13

W. G. Grenier 11-4-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-5

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

DATA: MoS_2 "In Situ" on 410 S.S., As Table #7 - Process #21 -- Thickness of Converted Film Compared with Various Mo Complex Electrodeposition Times

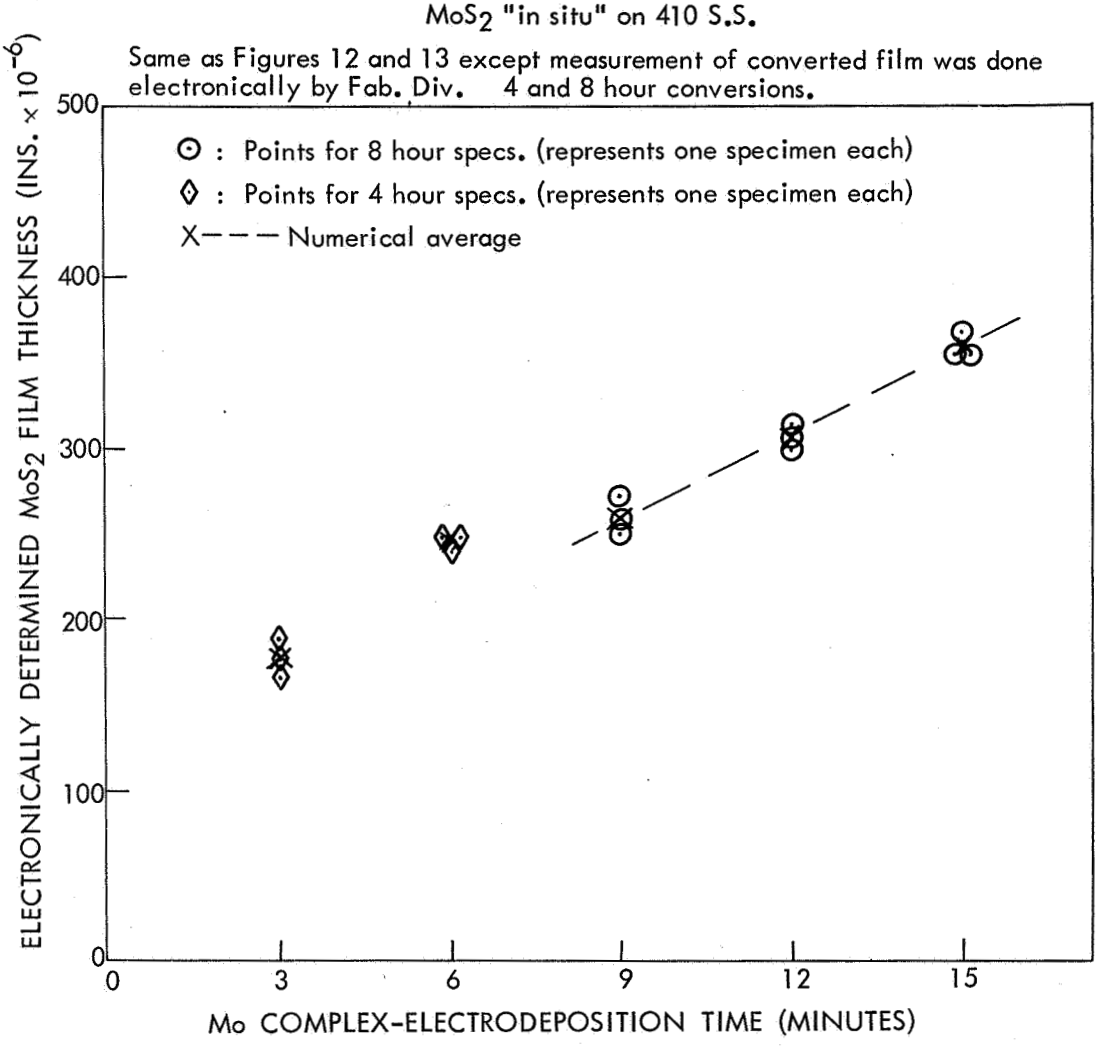


Figure 14

W. G. Grenier 11-4-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

M.R. 63-5

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
C. E. Vest	MoS_2 "In Situ"	673Y03-14	1200-41

CONCLUSIONS:

The work performed in this program has produced a process and capability of depositing MoS_2 "in situ" onto a number of space components. The coefficient of friction is comparable to natural MoS_2, the wear life is better than burnished MoS_2 but not as good as Epoxy bonded MoS_2, and can be deposited to a controllable thickness.

A T.N. has been written to cover the work performed and the results obtained.

Charles E. Vest 11-7-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
E. Divine	Beltsville	123	ATD	673Y19-05	1200-30

DATE IN	DATE COMPLETED	PERFORMED BY
4-16-63	5-13-63	W. G. Grenier

NAME OF TEST

Macro photographic study of slip ring assembly.

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Slip ring assembly No. 7, from vacuum slip ring test.

Assembly was run at 5000 rpm, 10^{-8} tor, for 50×10^{6} revolutions when it began to bind and become extremely noisy. Test was therefore discontinued.

All parts purportedly of 440-C stainless steel, Au plated all over.

Prior to running, a coating of MoS_2 was carefully applied to all bearing surfaces.

EQUIPMENT INVOLVED:

(1) Benzene and Alcohol soln, (2) Ultrasonic cleaning apparatus, (3) Model 'L', Macro Camera, (4) 32 mm, 48 mm, 72 mm, and 158 mm, lenses for camera, (5) Fluorescent lighting stage, (6) Polaroid camera attachment.

RESULTS:

One set of bearings was severely attacked, other set only mildly pitted.

All signs of Au were removed from roots and sides of bearing area in all raceways.

Plow tracks while evident in the raceways, did not appear to be severe.

For photomacrographs see Figures 1-11 on sheets 3-7, this report.

W. G. Grenier 5-13-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
E. Divine	T.R. 1200-30	673Y19-05	1200-30

PROCEDURE:

1) Clean all parts, ultrasonically, in Benzene and Alcohol

2) Employing the Bausch and Lomb Model 'L', Macro Camera, with flourescent lighting stage and polaroid camera back attachment, prepare Macro Photographs as follows:

2.1) at 2 diameters using the 158 mm lens at f-32

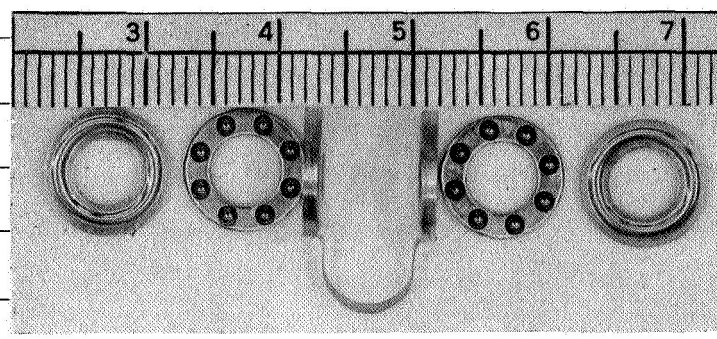
2.2) at 4 & 8 diameters using the 72 mm lens at f-22 and f-16

2.3) at 9 diameters using the 48 mm lens at f-11

2.4) at 15 & 20 diameters using the 32 mm lens at f-11 and f-16.

3) Verify magnifications by laying a millimeter scale on specimen and photographing it once with specimen. Measure scale in finished photograph to assure accuracy of magnification.

mm scale →



Shows method of using mm scale to verify magnification.

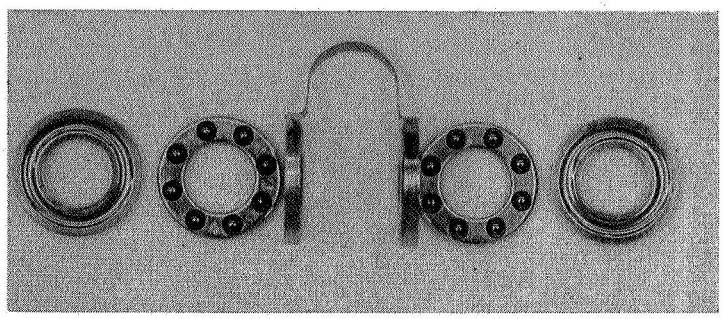
W. G. Grenier 5-13-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
E. Divine	T.R. 1200-30	673Y19-05	1200-30

DATA: Macro Photographs of Slip Ring Assembly No. 7



Assembly layout

Figure 1 2X

Retainers with smooth face up

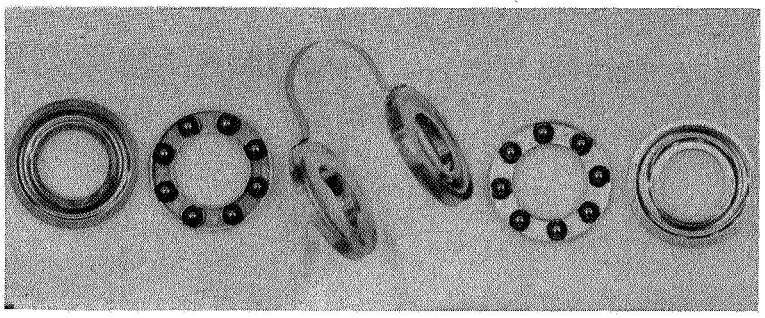


Figure 2 2X

Retainers with hollowed side up

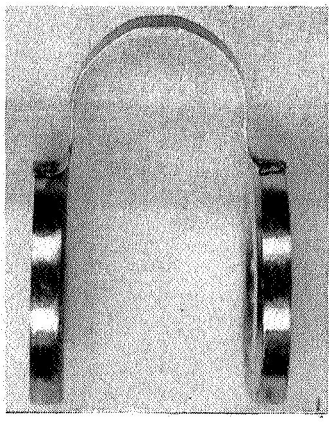


Figure 3 4X

Center races with conductor strap soldered to them. Shows solder joint.

W. G. Grenier 5-13-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
E. Divine	T.R. 1200-30	673Y19-05	1200-30
DATA: Macro Photographs of Slip Ring Assembly No. 7			

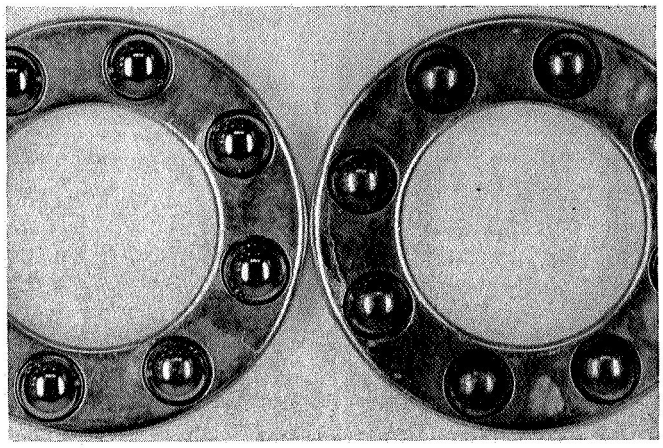


Figure 4 8X

Retainers: Smooth Faces

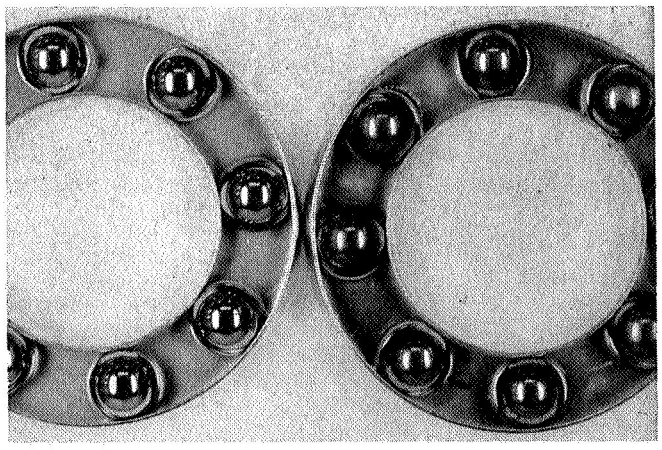


Figure 5 8X

Retainers: Hollowed Faces

Figures 4 and 5 show indications of pitting on bearing balls on right hand side of each figure.

W. G. Grenier 5-13-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
E. Divine	T.R. 1200-30	673Y19-05	1200-30

DATA: Macro Photographs of Slip Ring Assembly No. 7

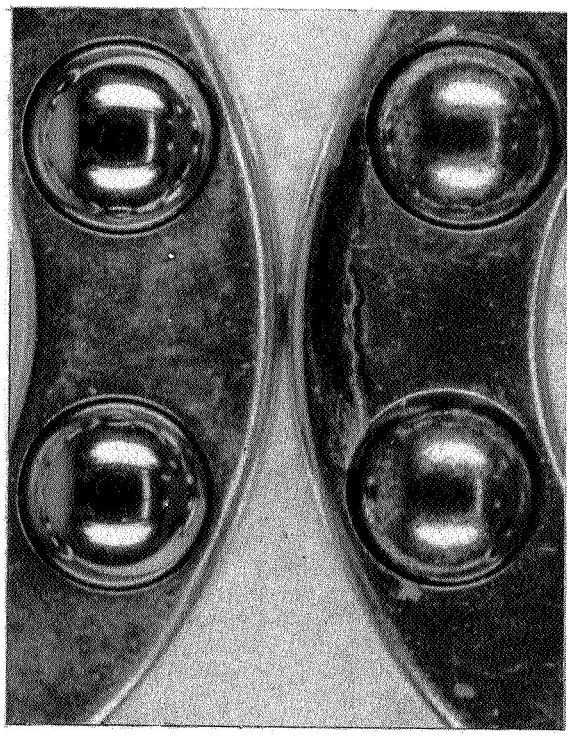


Figure 6 20X

Retainers: Smooth Face

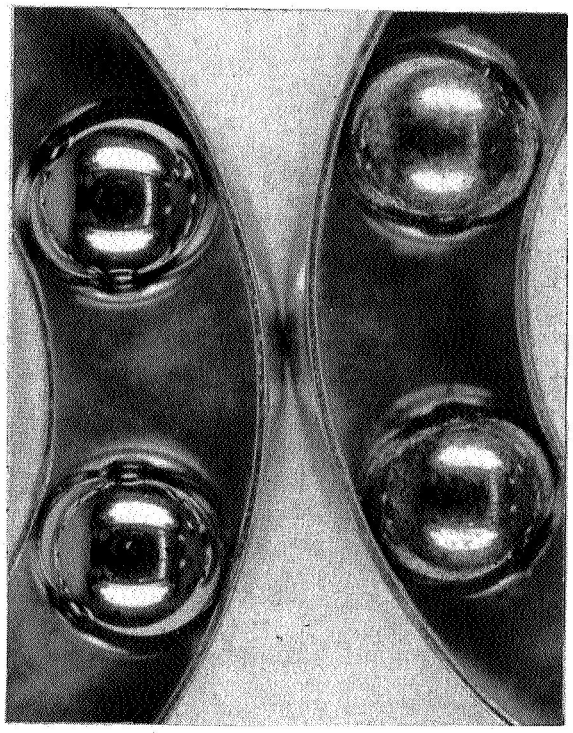


Figure 7 20X

Retainers: Hollowed Side

Shows severe attack on bearing balls in right hand retainers. Some apparent pitting is discernible in bearing balls on left hand side of each photomacrograph.

W. G. Grenier 5-13-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
E. Divine	T.R. 1200-30	673Y19-05	1200-30
DATA: Macro Photographs of Slip Ring Assembly No. 7			

Bearing Races

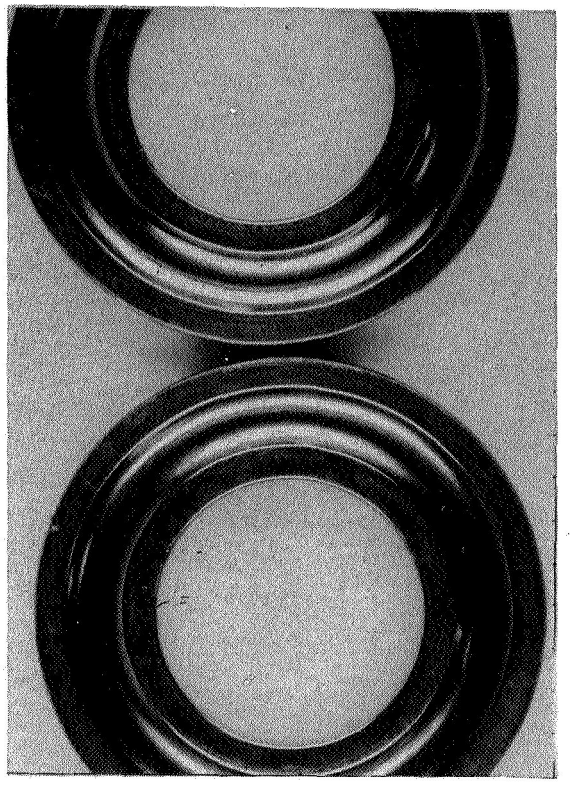


Figure 8 8X

Outer Races

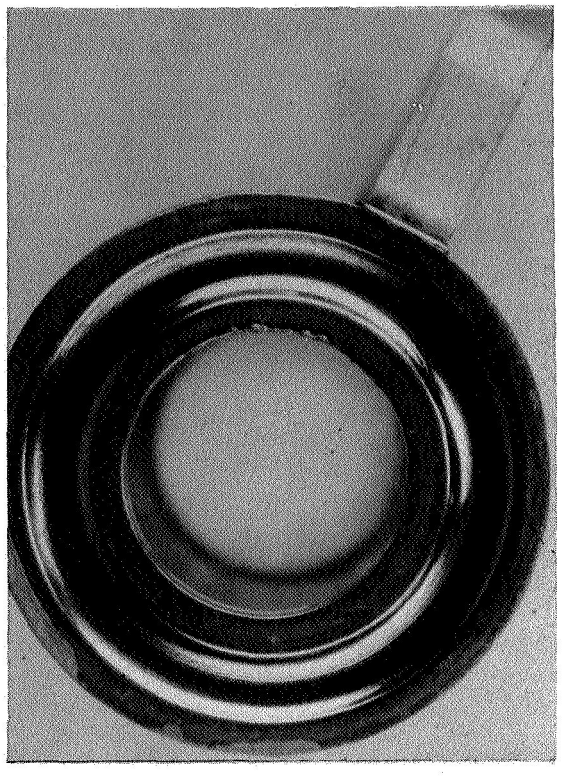


Figure 9 9X

Strapped Inner Race

No Au was discernible in raceway proper.

No abnormal wear signs were observed.

W. G. Grenier 5-13-63
(Signature) (Date)

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
E. Divine	T.R. 1200-30	673Y19-05	1200-30

DATA: Macro Photographs of Slip Ring Assembly No. 7

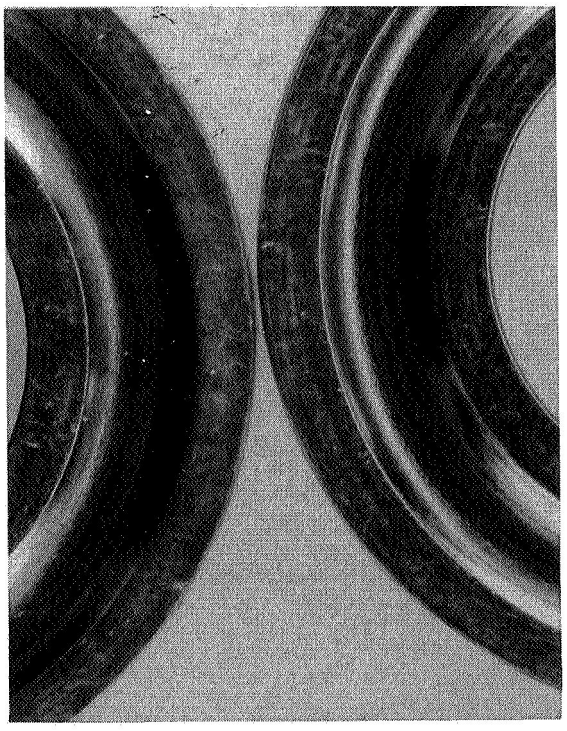


Figure 10 15X

Figure 11 20X

Bearing Races showing "Plow Tracks."

No Au is apparent in roots, or on the sides of the raceways.

W. G. Grenier 5-13-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
E. Devine	Beltsville	123	ATD	673Y19-05	1200-30

DATE IN	DATE COMPLETED	PERFORMED BY
9-16-63	9-19-63	J. L. Wall

NAME OF TEST

Macrophotograph study of Slip Ring Assembly

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Slip Ring assembly no. 13 coated by MoS_2 in situ for vacuum slip ring tests.

Assembly has run 60×10^6 revolution at 2000 R.P.M., in a vacuum of 10^{-8} tor. test was stopped when either the slip rings assembly or the support bearings of the test arrangement failed.

EQUIPMENT INVOLVED:

1. Model "L" Macro Camera
2. 32 mm and 158 mm lenses for camera
3. Polaroid Camera attachment
4. Fluorescent Lighting stage

RESULTS:

For results see sheet No. 3, figures 1 & 2

James L. Wall 9-26-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
E. Devine	S.R. 1200-30		1200-30

PROCEDURE:

Macrophotographs were taken using the Bausch and Lomb model "L" macro camera with a polaroid camera attachment. The specimens were placed on the macro stage and illuminated by means of a set of balanced fluorescent lights plus room lights. Camera settings for photographs taken were as follows:

Magnification	Lenses	F settings	Time
1-2 diameter	158 mm	32	2 sec's
15 diameter	32 mm	11	90 sec's

James L. Wall 9-26-63

(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
E. Devine	S.R. 1200-30		1200-30

DATA: Macrophotograph study of Slip Ring Assembly

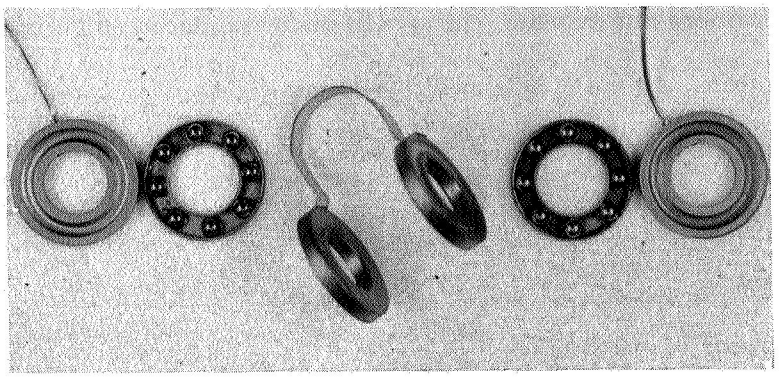


Fig. 1-2 X.

Macrophotograph showing exploded view of slip ring assembly. Gray coloration indicates presence of MoS_2 in Situ.

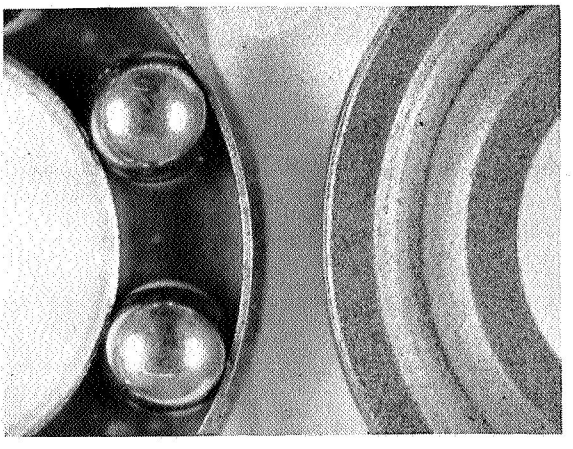


Fig. 2-15 X.

Macrophotograph showing what appears to be MoS_2 in root of race and on surfaces of bearing balls.

James L. Wall 9/26/63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
P. A. Studer	Beltsville	37	ATD	634Y19-05	1200-40

DATE IN	DATE COMPLETED	PERFORMED BY
2-15-63	2-25-63	W. G. Grenier

NAME OF TEST

Metallurgical Examination

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Determination of physical properties of a sample of Alnico 5, alloy, which purportedly had a preferred grain orientation.

1. Sample, Alnico V type, magnet alloy called Alnicus USM-75. Dimensions 0.438 × 0.325 × 1.28

EQUIPMENT INVOLVED:

Specimen mounting press, black bakelite, Handimet hand polisher, lapping wheels, Automet automatic Polisher, Various reagents, Unitron Metallograph Model-L macro camera, Polaroid camera backs, polaroid film, Kentron Microhardness Tester.

RESULTS:

1) Specimen hardness was Rockwell C-52

2) See Enclosure 1, for macrographic and micrographic results.

3) A composite of 36 photomicrographs, prepared at 67 magnifications has previously been submitted to the Originator

W. G. Grenier 2-25-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
P. A. Studer	ATD	634Y19-05	1200-40

PROCEDURE: It was desired to determine all possible information without destruction of the sample, if possible.

The sample was placed on end in a standard 1-1/4" dia. mold, and the mold filled to capacity with black bakelite powder. The powder was compacted around the sample, the mold opened and refilled with black bakelite powder.

Standard mounting procedures were, then followed for mounting in bakelite. However, the amount of bakelite in the mold proved to be inadequate, therefore the entire load of the piston was applied directly to the sample. This load is calculated to be approximately 30,000 psi, pure compression on the sample in a direction normal to the axes of symmetry of the grains. The sample, upon removal from the mold, was observed to be fractured in two places.

Photomacrographs were prepared showing a fracture surface, and the four faces of the sample.

Metallographic specimens were picked from the fracture segments to show microstructure in each of the three planes of the grains and establish the information desired by the originator.

Specimens 1, 2, & 3, were mounted, polished, etched, and photomicrographs and microhardness readings prepared.

P. A. Studer 2-25-63
(Signature) *(Date)*

S.R. No. 1200-40

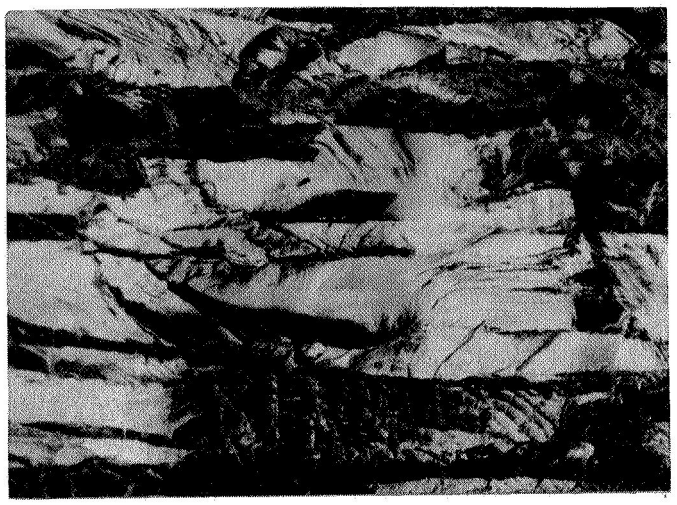


Fig. 1-Fracture face from compressive failure. 6-3/4 X.

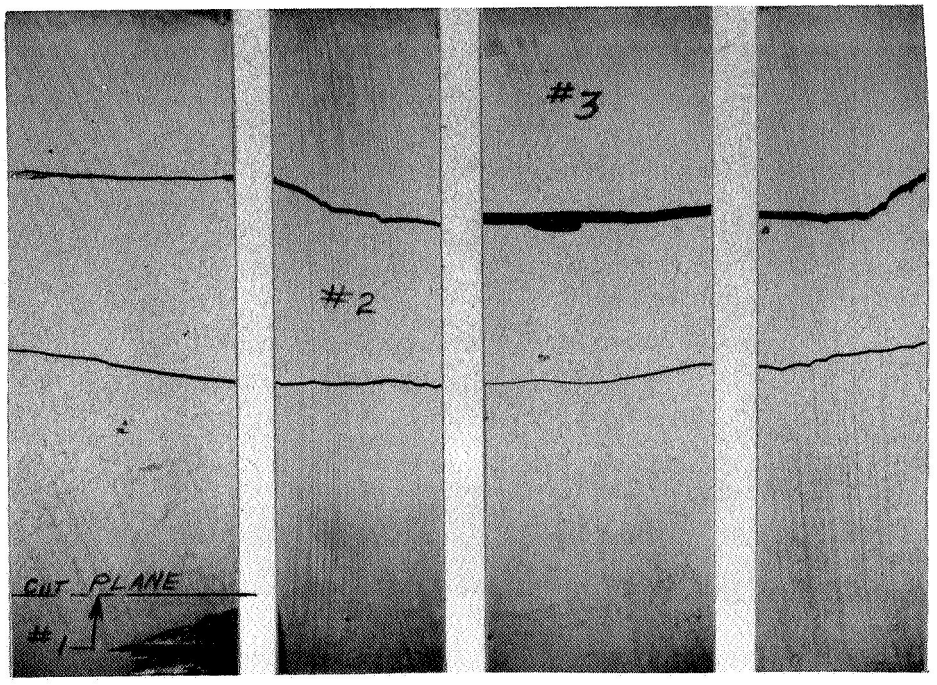


Fig. 2-Four faces of sample following fracture. 3 X.

Shows fracture orientation with respect to each face.

Numbers in red show faces and areas to be used for metallographic specimens.

Material: Alnico V, R/C-52.

S.R. No. 1200-40

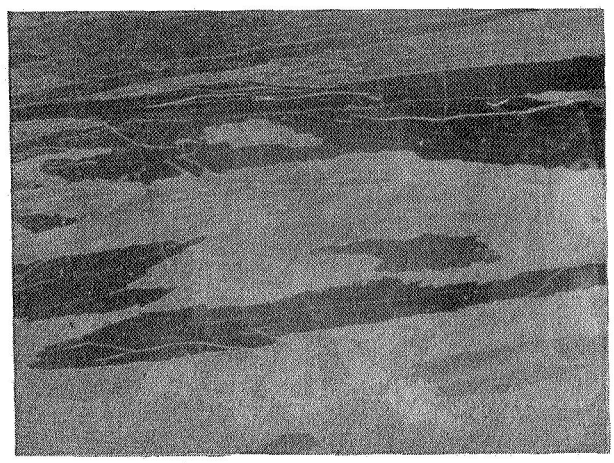


Fig. 3-Specimen No. 1, *fracture plane.* 8 X.

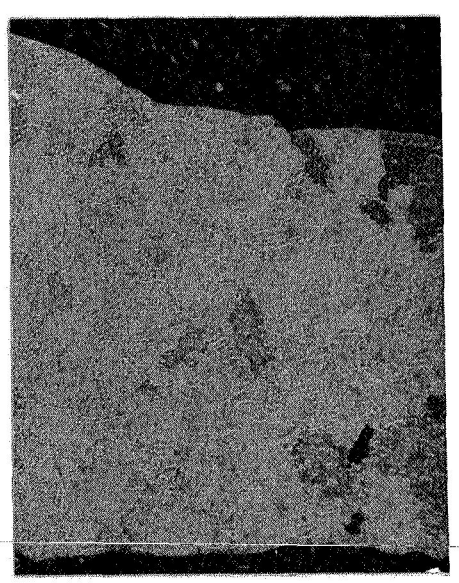


Fig. 4-Specimen No. 2. Grain ends. 8 X.
No observable elongation.

Fig. 5-Specimen No. 3. 8 X.
Plane normal to Figs. 3 and 4.

Etchant for above Photomacrographs: $FeCl_3 + HCl + H_2O$

Photomacrographs, Figs 3, 4, & 5, showing coarse, orientated columnar grains with internal stratification. No complete grain is visible in any specimen.

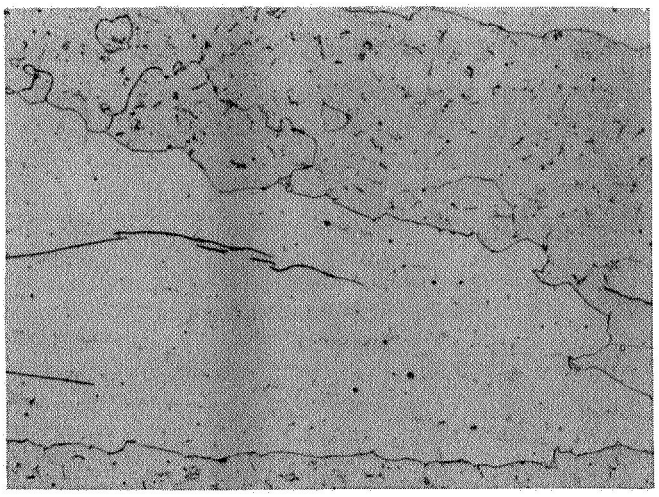


Fig. 6-Specimen No. 1. 67 X.

Plane of fracture: Parallel to grain axis of symmetry. Shows no abnormality in irregularity of grain.

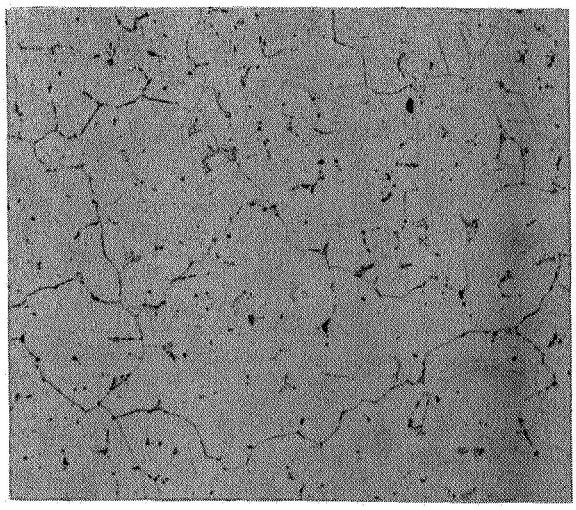


Fig. 7-Normal Etch. 67 X.

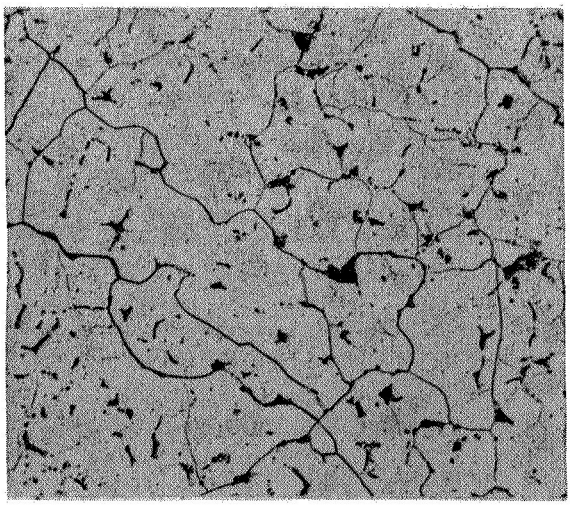


Fig. 8-Overetched. 67 X.

Specimen No. 2.

Plane normal to grain axis of symmetry. Shows no observable elongation.

Etchant for all above: $FeCl_3 + HCl + H_2O$

Material: Alnico V, R/C-52

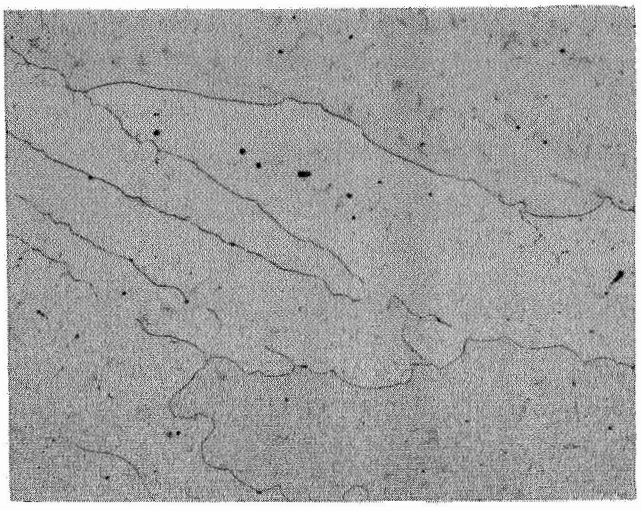


Fig. 9-Specimen No. 3. 67 X.

Plane normal to plane of fracture but parallel to grain axis of symmetry.

Material: Alnico V, R/C-52

Etchant: $FeCl_3 + HCl + H_2O$

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
P. A. Studer	ATD	634Y19-05	1200-40

CONCLUSIONS:

Tests established that manufacturers claim of fully oriented grain structure was correct and that directionality was within a few degrees of the specified plane.

Grain length greater than the physical length of the specimen (.375") indicates optimum magnetic properties can be anticipated from this process.

C. E. Vest
Philip A. Studer
(Signature) (Date)

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
R. Andryshak	6	S-204	ATD	634Y03-13	1200-34

DATE IN	DATE COMPLETED	PERFORMED BY
11-14-62	11-16-62	W. G. Grenier

NAME OF TEST

Microscopic Examination and Mechanical Polishing of Ceramic

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

1) Determine penetration of Ga alloy into a ceramic disc.
2) Determine feasibility of utilizing metallurgical polishing apparatus to polish two ceramic discs to a 4 rms finish.

ARTICLES TESTED

1) One COORS AD-85 $Al_2 O_3$ disc, 2" dia × 1/8" thick, with Ga alloy stain on imprinted surface.
2) Two of the same type discs with no stain.

EQUIPMENT INVOLVED:

Specimen mounting press, cut-off wheel, SiC polishing papers, polishing laps, Unitron metallograph, and Brush Surfindicator.

RESULTS:

1) Observation at 1000 magnifications showed no apparent penetration of the Ga into the ceramic.

2) Surface finish, as measured on the Brush Surfindicator, is probably between 8 and 16 microinches.

W. G. Grenier 11-16-62
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. Andryshak	ATD	634Y03-13	1200-34

PROCEDURE:

1. The stained specimen was broken in the stained area, sectioned on the cut-off wheel, mounted in lucite, and polished through the papers and wheels. Following the final polish it was observed at approximately 1000 magnifications.

2. One sample was polished on the face opposite the lettering. The sample was polished for better than four (4) hours, wheel contact time, using 1/4μ diamond abrasive.

W. G. Grenier 11-15-62
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. Andryshak	ATD	634Y03-13	1200-34

CONCLUSIONS:

1. Specimen #1 (COORS AD-85 Al_2O_3 disk with Gallium Stain). Gallium was originally wetted to specimen via ultrasonic vibration; the Gallium stained the disc and ultrasonic cleaning would not remove the stain; it was felt that the Gallium had alloyed with the Al_2O_3 and penetrated it. The results of this test show that the stain is only a surface phenomenon.

2. Specimens # 2 and 3 will be polished to a 4 μ-in. rms finish by the shop and then tested for wettability as before, to attempt to determine the effect of surface finish on Gallium wetting to 85% Al_2O_3.

Richard J. Andryshak
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
F. Federline	Bltsvl.	39	ATD	673Y03-13	1200-10

DATE IN	DATE COMPLETED	PERFORMED BY
4-9-63	4-9-63	W. G. Grenier

NAME OF TEST

Passivation Treatment

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Passivate 6 stainless steel (type 303) bearing shafts and reduce corrosion products.

3 shafts, 1/4" dia. × 3" long.

3 shafts, 1/4" dia. × 6" long.

EQUIPMENT INVOLVED:

Hot plate, H NO_3, Na_2 Cr_2O_7, Beaker, and centigrade thermometer.

RESULTS:

Shafts passivated and returned to Originator as requested.

W. G. Grenier 4-9-63
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
F. Federline	ATD	673Y03-13	1200-10

PROCEDURE: Prepare 1000 ml each of the two following solutions:

Soln.-1, 20 v/o HNO_3

2 w/o $NA_2 Cr_2 O_7$

78 v/o H_2O

Soln.-2, 5 w/o $Na_2 Cr_2 O_7$ in H_2O.

Fill 1000 ml beaker with solution #1. Place on hot plate and heat to between 45-55°C. Immerse shafts in solution, and hold at temperature for 1/2 hour.

Transfer shafts to 1000 ml beaker filled with solution #2 and hold at 60-70°C for one (1) hour.

Remove shafts and submit to originator.

W. G. Grenier 4-9-63

(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	BUILDING	ROOM	PROJECT	JOB ORDER NUMBER	REQUEST NO.
R. Andryshak	Belts	38	ATD	634Y03-13	1200-16

DATE IN	DATE COMPLETED	PERFORMED BY
12-5-62	12-31-62	W. G. Grenier

NAME OF TEST

Alloy Preparation

DESCRIPTION OF SERVICE OR ARTICLE TESTED:

Prepare alloy as follows:

Ga - 62% by wt.
In - 25% by wt.
Sn - 13% by wt.

EQUIPMENT INVOLVED:

Beaker, Hot plate and Beam balance.

RESULTS:

Alloy poured from beaker to specimen bottle and submitted to F. Kocker, Bldg. 6, Rm. S-213 for use. Total alloy transferred to specimen bottle - 19.5 grams.

W. G. Grenier
(Signature) *(Date)*

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. Andryshak	ATD	634Y03-13	1200-16

PROCEDURE:

Weigh empty beaker.

Add 2.6 grams Sn.

Heat Sn to melting point, add 5 grams In and blend.

Add 12.5 grams Ga and blend.

Cool alloy to room temperature.

Total alloy weighs 20.1 grams.

(Signature) (Date)

SERVICE REPORT

STRUCTURAL AND MECHANICAL APPLICATIONS SECTION

ORIGINATOR	PROJECT	JOB ORDER NUMBER	REQUEST NUMBER
R. Andryshak	ATD	634Y03-13	1200-16

CONCLUSIONS:

Thank You Very Much. Mixture is satisfactory.

R. J. Andryshak

(Signature) *(Date)*